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The Barnes and Houdek Soils Their Morphology and Classification

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THE BARNES AND HOUDEK SOILS THEIR MORPHOLOGY AND CLASSIFICATION

BY

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THE BARNES AND HOUDEK SOILS THEIR

MORPHOLOGY AND CLASSIFICATION

This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser

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OPO

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The differentiation of soils into separate series is difficult when morphological characteristics change gradually over a broad geographic area. Where a natural feature such as a prominent end moraine or a change in the composition of the parent material is lacking this problem of separation is more acute. This happens where the soil forming factors of parent material, time and relief are constant over a large area in which the climatic change is gradual. Such an area occurs in east central North and South Dakota, and western Minnesota.

Early classification schemes used geographically related soil types. Differences in the genesis and morphology of soils were not used. The result was that one soil would cover a large area, such as the one above. The revision of the series concept by Marbut (25) in the 1920's brought the differences in genesis and morphology into prominence with the result that soils are now being separated by these criteria.

Glacial till of Wisconsin age occurs in eastern North and South Dakota and western Minnesota as an undulating plain of moderate local relief. Climatic conditions range from moist subhumid mesothermal to dry subhumid microthermal (36). The climatic boundaries are diffuse and may shift markedly from one year to another.

Until 1945 the Barnes series (2) and its catenal associates were the dominant glacial till series of this broad region. In 1945 the Vienna (45) followed by the Houdek in 1954 (47) and the Poinsett in 1956 (48) and their catenal associates were separated from the Barnes. Figure 1

shows the extent of the Barnes area in 1938 and Figure 2 the extent in 1957.

This study will cover the Houdek-Barnes relationships and the Barnes relationship among the three states. The Houdek was separated from the Barnes to delineate soils with a textural B horizon and lighter colored browner A horizons. The line separating the Houdek from the Barnes soils has not been determined.

One purpose of this study is to compare the characteristics and soil forming factors of the Barnes and Houdek soils and to make a recommendation as to the best place they may be separated. A second purpose is to determine how the Barnes soils in Minnesota compare with those in North and South Dakota.

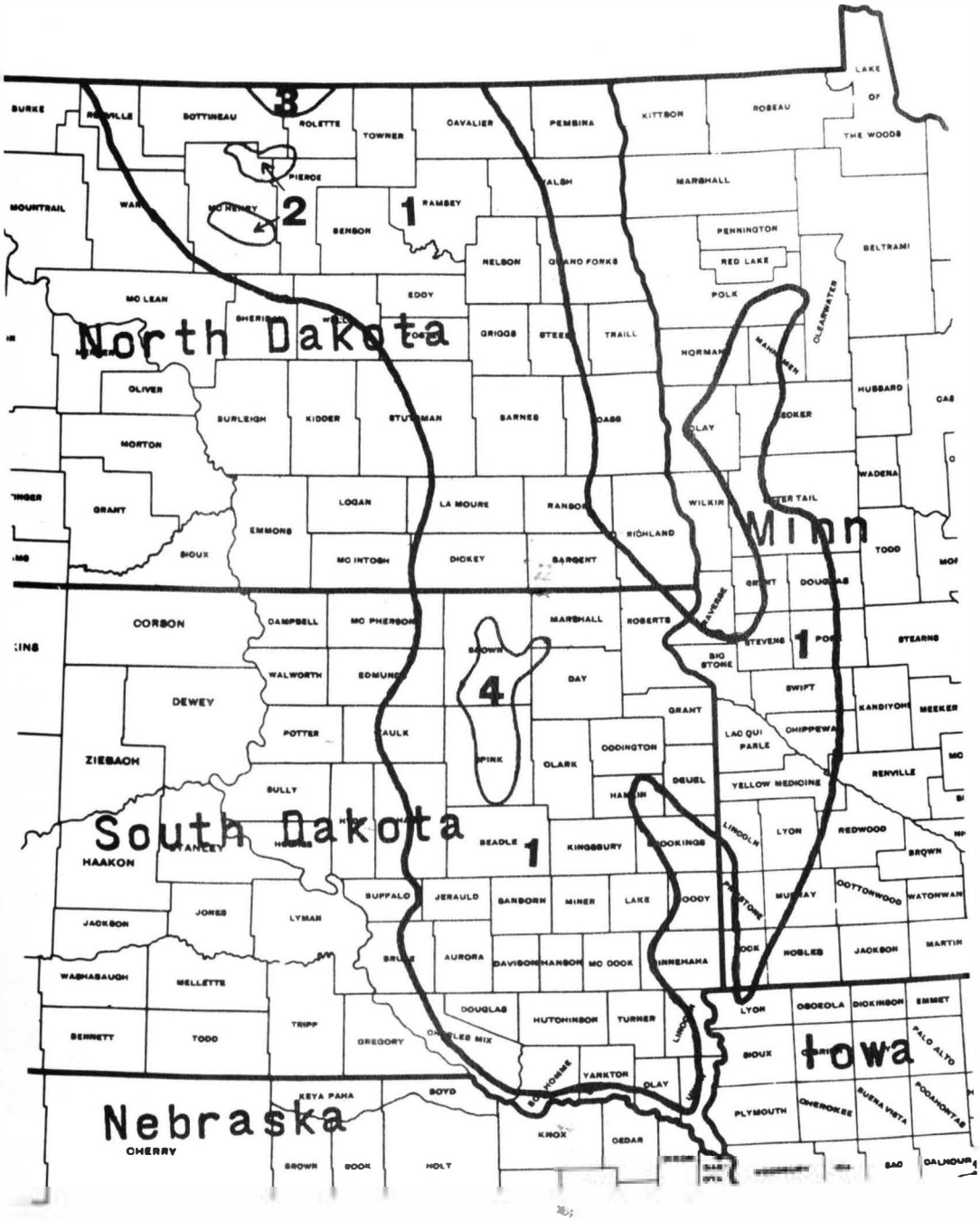

Figure 1. The Barnes Area in 1938

1- Barnes-Parnell
2- Valentine-Nuecess-Dune sand
3- Taylor-Nebish
4- Fargo-Beardon

Source: Yearbook of Agriculture, Soils and Men (38)

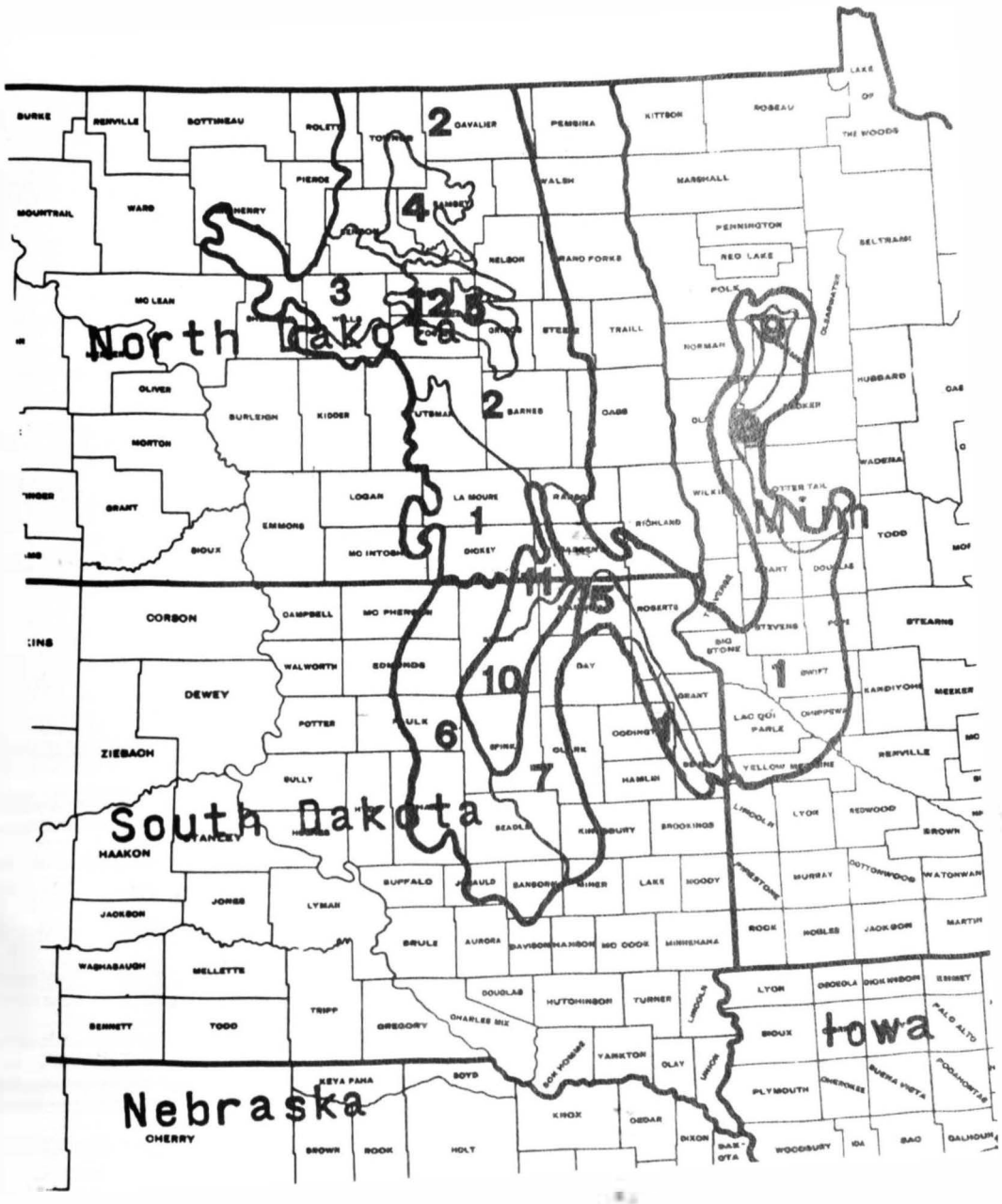

Figure 2. The Barnes Area in 1957

1- Barnes-Aastad
2- Aastad-Hamerly-Barnes
3- Barnes-Gardena-Lovell
4- Beardon-Barnes
5- Barnes-Buse
6- Houdek-Bonilla
7- Beadle-Houdek
8- Waukon-Barnes
9- McIntosh-Winger
10- Beotia-Aberdeen
11- Hecla-Ulen
12- Lovell-Garden -Fordville

Source: North Central Regional Publ. No.76 (40)

REVIEW OF LITERATURE

History of the Glacial Till Soil Series

Concept of Soil Series

The series concept was first used in 1903 (35). As it was then used it covered geographically related soil types. The principle criteria for series separations were kind of parent material; color, number, and thickness of horizons; and the texture of the profile. In 1921 (23) and 1922 (24) Marbut proposed the change of emphasis from geographical relationships to the features within a soil profile. In 1927 (25) he stated that the soil type should be determined by eight characteristics of the soil; namely the texture, number, arrangement, thickness, color, structure and chemical composition of horizons, and the parent material. Baldwin, Kellog and Thorp in the 1938 Yearbook of Agriculture (38) define a soil series as "a group of soils having horizons similar as to differentiating characteristics and arrangement in the soil profile and developed from a particular type of parent material".

History of Soil Series Used in Glaciated Areas

The first series used for mapping in glaciated areas was the Miami in 1900 (10). It was correlated in Montgomery County, Ohio and described as a light loam over a heavy clay loam subsoil. The parent material was scratched Niagara limestone or clay filled with angular boulders and pebbles. The present concept calls the Miami a modal Gray-Brown Podzolic soil developed from highly calcareous glacial till. It was at first mapped from Washington to New York and North Dakota to

Missouri but is now restricted to Michigan, Ohio, Indiana and Wisconsin.

The Marshall series was first correlated in a soil survey of the Marshall Area, Minnesota in 1903 (49). The 1904 Instructions to Field Parties (37) differentiates the Marshall from the Miami on color. The Marshall soils were called dark-colored upland soils of the glaciated and loessial region with the Miami soils being the light colored. The present concept of the Marshall series restricts the soil to deep, dark colored, well drained medial Brunizems developed from medium textured deposits of calcareous Wisconsin loess. The soil was first mapped from Louisiana to North Dakota and Kansas to Indiana but is now restricted to Iowa, Missouri, and Nebraska.

The immediate parent of the Barnes series was the Carrington. This series was established in a soil survey of the Carrington Area, North Dakota in 1905 (22). However in this survey it was called a soil developed from sedimentary deposits, not glacial till. A soil survey of Rice County, Minnesota in 1909 (4) used the Carrington as the glacial drift soil and restricted the Marshall to loessial deposits. The Carrington series was described as having 12-24 inches of brownish black silty loam grading into a heavy yellow clay filled with stone fragments. A soil survey of Bremer County, Iowa in 1913 (6) separated the Carrington and Miami series. This survey established the Carrington as a prairie soil and the Miami as a timbered soil. The present concept as described in a soil survey of Cerro Gordo County, Iowa in 1940 (11) further limited the Carrington to a prairie soil formed from Mankato age glacial till. As first mapped on glacial till the Carrington was used from North Dakota to Indiana and Missouri. At the present time, it is

restricted to southeastern Nebraska.

The Barnes series was first correlated in a soil survey of LaMoure County, North Dakota in 1914 (2). The Barnes soils were separated from the Carrington on the basis of salinity in the subatrata, the Barnes being the non-saline soil. The type location was established in Grant County, South Dakota in 1922 (44). It was characterized at that time as having a surface layer 5-10 inches deep of black or almost black friable loam of very fine granular structure, underlain by a brown friable heavy silt loam, granular but coarser than the surface. At 18 to 24 inches was a layer of lime accumulation, grayish brown or yellow in color and averaging 12 inches thick. Below this was the parent material, grayish yellow in color with lime present in white spots but less numerous than the layer above. Glacial boulders and gravel occur throughout the profile. Following the treatise of Marbut (25) definite layers had been recognized and an attempt made to describe them.

The extent of the Barnes series as mapped in 1938 is shown by Figure 1. With the exception of the Beadle series, described as a clay-pan soil in 1920 (43), the Barnes series was used for well-drained Chernozem soils of the Wisconsin glacial till until 1945. The Vienna series was proposed in that year and established with a soil survey of Rock County, Minnesota in 1949 (45). The Vienna was separated from Barnes on the basis of a thicker sola, little or no salt in profile and developed on Iowan and Tazewell substages of the Wisconsin glaciation.

The next major separation from the Barnes was the Houdek series in 1954. The Houdek was established in a soil survey of Spink County, South Dakota in 1954 (47). This series was separated on the basis of

being a Chernozem intergrading to Chestnut and having a slight accumulation of clay in the B horizon. Also it has a saline substrata where the Barnes apparently does not. The third separation was the Poinsett series in 1956. This was established in a soil survey of Brookings County, South Dakota in 1956 (48). It was separated from Barnes on the basis of being developed from stratified silty drift of the Cary substage of the Wisconsin glaciation while Barnes is developed in loam glacial till of the Mankato substage of the Wisconsin glaciation.

Figure 2 shows the extent of the Barnes series in 1957. The decrease in area is due mainly to the establishment of the Vienna, Houdek and Poinsett series. Special note should be made of the Houdek-Barnes boundary along the North-South Dakota border. As stated earlier this study will only be concerned with the Barnes-Houdek relationships.

Present Concept of the Barnes and Houdek Series

The location of the central concept of the Barnes series is in Barnes County, North Dakota. The exact location of the type site is 400 feet north and 90 feet west of southeast corner of Section 20, Township 142 North, Range 56 West. The Barnes soils are described by C. A. Mogen and W. M. Johnson (30) as:

> . . . well-drained Chernozems developed in calcareous loam and clay loam glacial till of late Wisconsin (Mankato) age. These soils have developed under a tall-grass vegetation in the cool-temperate, dry-subhumid Northern Great Plains. Mean annual temperature ranges from 36 to 44° F., average annual precipitation ranges from 16 to 22 inches. The Barnes soils have thick, black, very friable, granular A_1 horizons high in organic matter; dark grayish-brown, friable, prismatic-blocky B horizons with very little or no clay accumulation; and moderately developed horizons of calcium carbonate and gypsum accumulation in light olive-brown, friable, calcareous till. The Barnes soils

have thinner, grayer A_1 horizons, stronger colored and more strongly prismatic B horizons, and thinner sola than the Clarion soils of the moist subhumid region. They have thicker, darker, and grayer A_1 horizons and less strongly prismatic B horizons than the Williams soils of the Chestnut (moist semiarid) soils zone. The Barnes soils are the well-drained zonal soils of the Buse-Barnes-Aastad-Hamerly-Flom-Parnell catena. The Flom and Parnell soils are Humic-Gley soils on flats and in closed depressions. The Barnes soils occupy milder slopes than the Buse soils (Regosols) and higher positions and stronger slopes than the Aastad (moderately well-drained zonal soils) and Hamerly (high-lime Regosols) soils. Buse and Hamerly soils do not have B horizons. Aastad soils have thicker A horizons, duller-colored B horizons, and thicker sola than Barnes soils.

The location of the central concept of the Houdek series is in Spink County, South Dakota. The exact location of the type site is 400 feet west of southeast corner Section 10, Township 119 North, Range 65 West. The Houdek soils are described by C. A. Hogan (28) as:

> . . . well-drained, medium-textured Chernozem-Chestnut intergrades developed in friable loam or light clay loam glacial till of late Wisconsin age (Mankato substage). They have dark grayish-brown soft granular A_1 horizons; brown hard prismatic-blocky B_2 horizons; and a moderately developed horizon of calcium carbonate accumulation starting at depths of about 14 inches, in pale yellow calcareous loam glacial till. The Houdek series are the most extensive soils of the Orient-Houdek-Bonilla catena on the till plain in the upper James River basin in South Dakota. The Houdek soils occupy milder slopes than the associated Orient soils (Regosols), and steeper slopes and slightly higher positions than the associated Bonilla (Chernozem) soils on the undulating ground moraine. Associated soils with restricted drainage include the Cresbard (solodized-Solonetz), the Cavour (Solonetz), and the Tetonka (Solod) series. The Houdek series occupies the same position on the ground moraine as does the Barnes series in a slightly cooler moister climate and differs from the latter in having a slight accumulation of clay in the B horizon; a slightly lighter color and stronger chroma in the A_1 horizon; and a lower organic carbon content in the solum. The Houdek soils are differentiated from the associated Bonilla soils by their thinner sola; thinner A_1 horizons; and lighter color and stronger chroma in the B_2 horizons.

As can be seen from these descriptions, the Houdek has slightly more clay in the B horizon and is developed in a warmer drier climate.

The climate is expressed in the native vegetation of these soils. In the Houdek area the native grasses were primarily mid and short grasses while in the Barnes area they were tall and mid-grasses (1, 22).

THE GEOGRAPHICAL SETTING

Description of the Area

Geographical

The general geographical area that this study will encompass is the eastern half of North and South Dakota and the western half of Minnesota. This is very close to the east-west geographical center of the United States and relatively close to the Canadian border.

Physiography

This area lies at the western limit of what Fenneman (12) calls the central lowland province. Fenneman and Rothrock as revised by Flint (13) call the central part of the region, northeastern South Dakota, extreme western and south central Minnesota, and extreme eastern North Dakota, the Red River-Minnesota River lowlands. South of the lowlands in South Dakota and Minnesota lies the Coteau des Prairies. This coteau is 700 to 800 feet higher than the lowland in the northern end and 100 to 200 feet higher in the southern. West of the Prairie Coteau in South Dakota and extending westward to the Coteau du Missouri is what Flint (13) calls the James River lowland. In North Dakota this area between the Red River-Minnesota River lowland and the Coteau du Missouri is called the Drift Prairies by Hainer (14). Fenneman (12) calls the area east of the Red River-Minnesota River lowland in Minnesota the Superior upland. These areas are shown in Figure 3.

The elevation above sea level of the Red River-Minnesota River lowland is about 1000 feet. The Prairie Coteau ranges from 1400 to

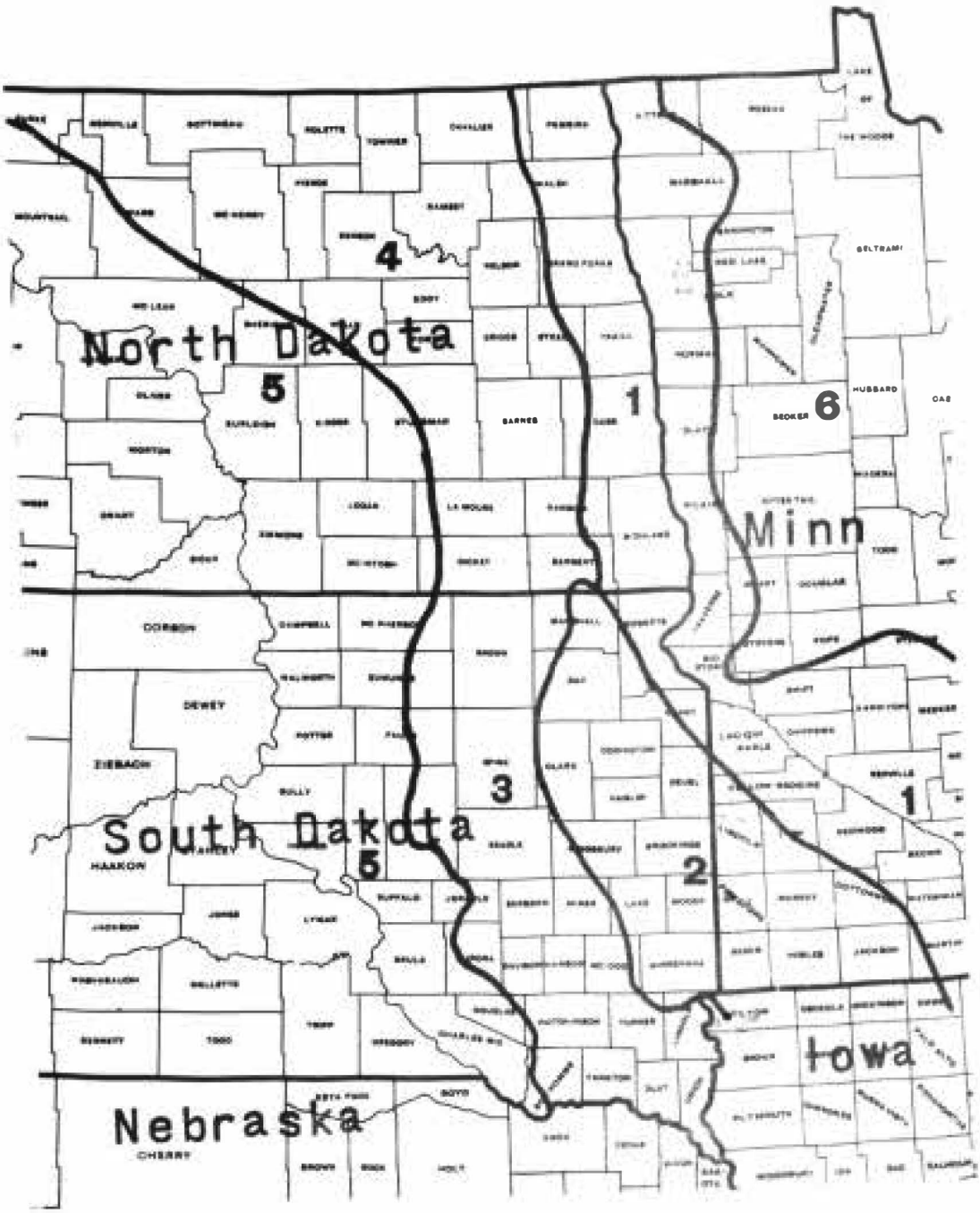

Figure 3. The Physiographic Provinces

1- Red River-Minnesota River lowland
2- Coteau des Prairies
3- James River lowland
4- Drift Prairies
5- Coteau du Missouri
6- Superior upland

Source: Flint (13), Fenneman (12) and Hainer (14)

2200 feet above sea level from south to north. The James River lowland and the Drift Prairie ranges from 1300 to 2000 feet south to north. The Missouri Coteau ranges from 1700 to 3000 feet south to north and the Superior upland from 1600 to 2000 feet above sea level.

THE SOIL FORMING FACTORS

Parent Material and Time

The soil parent material of the area of this study is glacial till. The Pleistocene or glacial period was characterized by four major glaciations. They were, from the oldest to the most recent: Nebraskan, Kansan, Illinoian and Wisconsin. The Wisconsin is in turn subdivided into four substages: Iowan, Tazewell, Cary and Mankato (13). The most recent of these, the Mankato, has covered the earlier glaciations almost entirely in North Dakota (14). In eastern South Dakota all four substages are evident. In the Prairie Coteau area they have not been over-ridden by the Mankato (13). In Minnesota the Tazewell is buried but the other three and possibly a drift sheet younger than the Mankato, the Valders, is evident (51).

The extent of the various substages is shown in Figure 4. A recent paper by Wright and Rubin (52) indicates that there may be some conflict as to the age of these areas. Radiocarbon dating seems to indicate that at least part of the Mankato area is of Cary age. For the purposes of this study the areas as shown in Figure 4 will be considered correct.

The parent material of all the soils studied is mankato glacial till. This parent material according to Wright (51) and Flint (13) is 11,000 to 12,000 years old. It was deposited by the receding glacier at approximately the same time. The assumption will be made that the mineralogical makeup is approximately the same. The till is generally loam in texture and contains according to stone counts by Flint (13)

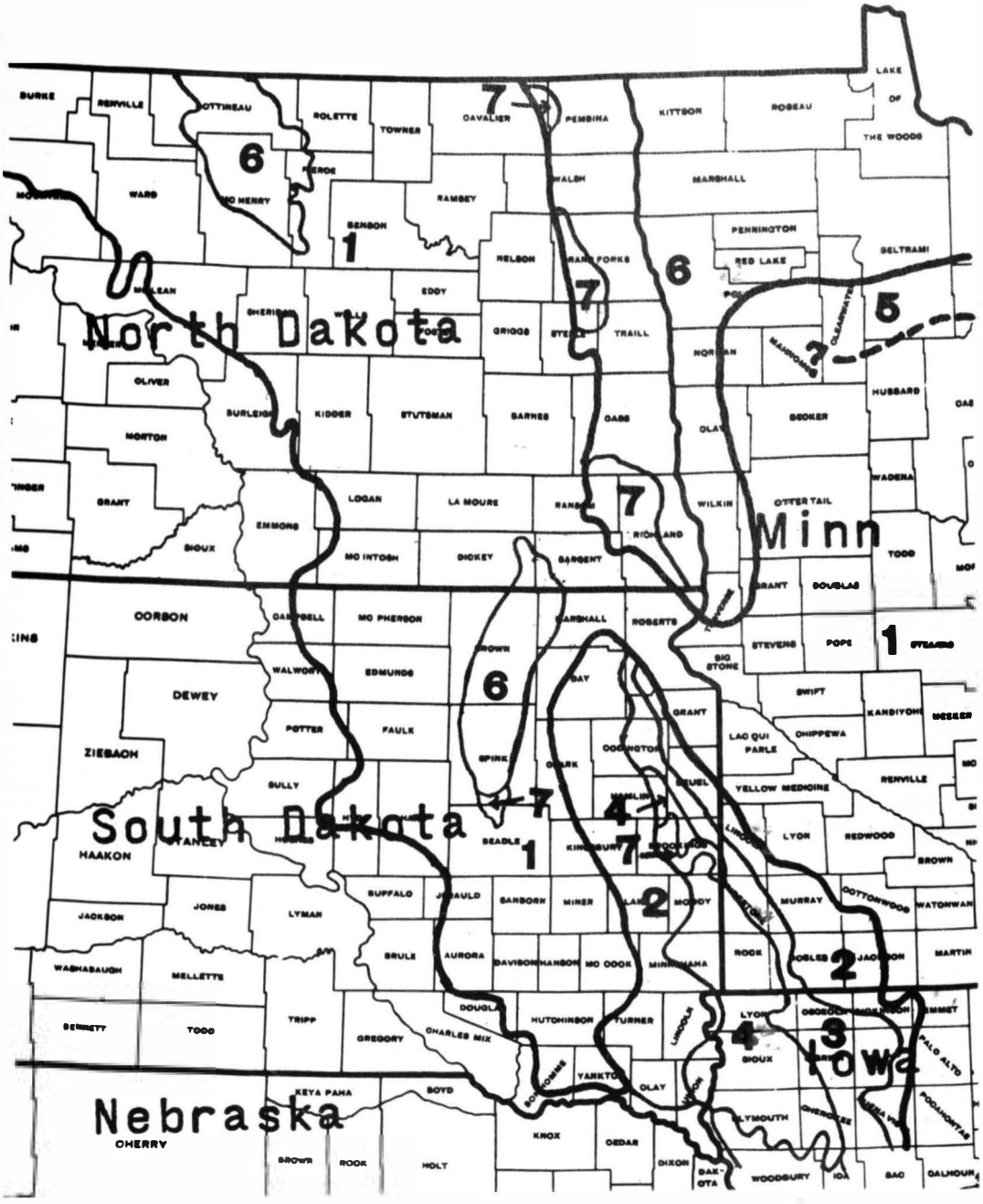

Figure 4. The Extent of the Mankato Glaciation

1- Mankato
2- Cary
3- Tazewell
4- Iowan
5- Valders
6- Glacial lake sediments
7- Outwash and alluvium

Source: Flint (13), Hainer (14) and Wright (51)

the following rocks and minerals: granitic rock, basic igneous rock, foliated metamorphic rock, quartzite, sandstone, limestone and dolomite, chalk, shale, vein quartz, chert, chalcedony, and iron oxide concretions. Limestone and dolomite outnumber granitic rock in the pebble-sized grade but in boulder sizes the granitic types far outnumber the other types.

Relief

The Mankato till area has an irregular surface topography (13). The till surface is characterized by little or no surface drainage, many depressions, nearly level to short choppy slopes, and very prominent terminal moraines.

The Mankato till plain has a young surface drainage pattern. The few streams have a very low gradient and the large number of morainic depressions are not connected by any drainage system.

The slopes on the till plain, except in terminal moraine areas, are in the range of two to six percent. Much of the area is nearly level with a local relief differential, from the crest of knolls to the bottom of the depressions of one to three feet. On the undulating areas the local relief difference is in the range of six to fifteen feet. The landscape on the Mankato area in general is a series of highs and lows with a comparatively short distance between two highs.

The Altamont moraine, a terminal moraine of the Mankato, is a prominent feature of the landscape. The moraine follows the southern and western limits of the Mankato area as shown in Figure 4. The moraine rises about 300 to 400 feet above the surrounding till plain.

Climate

The average annual air temperature is shown in Figure 5 and the average annual precipitation in Figure 6. As shown in Figure 5 the northern half of the area is in the 36 to 43 degree temperature range and the southern half in the 43 to 49 degree range. Figure 6 shows that most of western Minnesota and the southeastern corner of South Dakota is in the 21 to 27 inch precipitation range. The rest of the area is in the 15 to 21 inch range.

The climate of the Dakotas area has been classified as dry subhumid by Thornthwaite (36). The Minnesota area was classified by him as moist subhumid. These divisions are shown in Figure 7.

The entire area is characterized by cold dry winters and warm relatively moist summers. The average frost free season ranges from 120 to 145 days from the northern to the southern part of the area (39, 7, 42). The normal annual evaporation from pans ranges from 40 to 55 inches from the northern to the southern part of the area (42, 7).

Vegetation

One of the dominant factors that influence the development of a Chernozem soil is the vegetation. This vegetation, specifically grasses, influences the formation of the typical zonal soil through the process of calcification (38).

The Dakotas and Minnesota lie in the region of the United States known as the Prairies and Great Plains. In these areas the dominant native vegetation was grass. The tall grasses were dominant in the eastern part. With the decrease of precipitation to the west the mid-

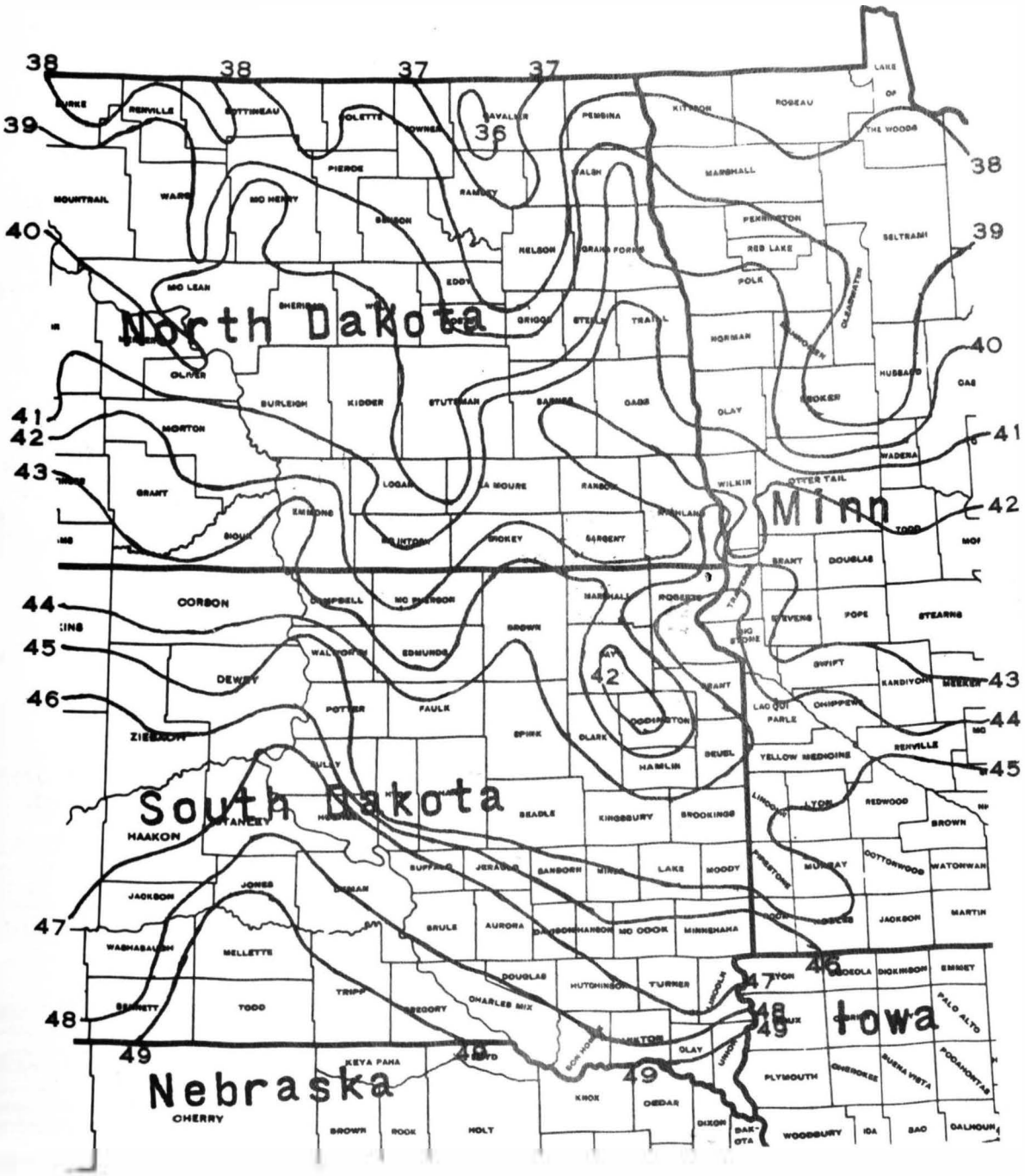

Figure 5. Average Annual Air Temperature in degrees Fahrenheit

Source: U. S. Weather Bureau Data (41)

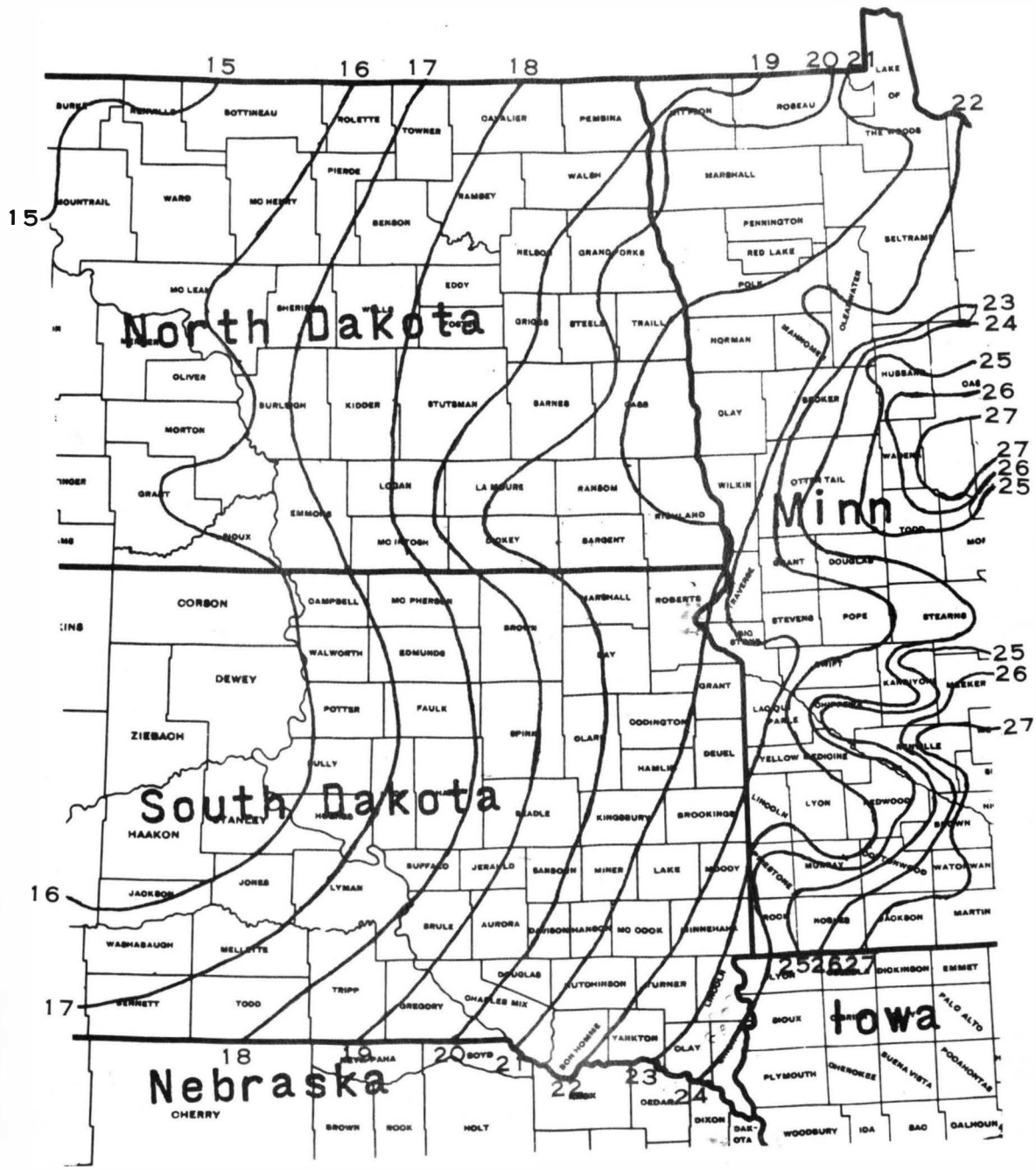

Figure 6. Average Annual Precipitation in inches per year

Source: U. S. Weather Bureau Data (41)

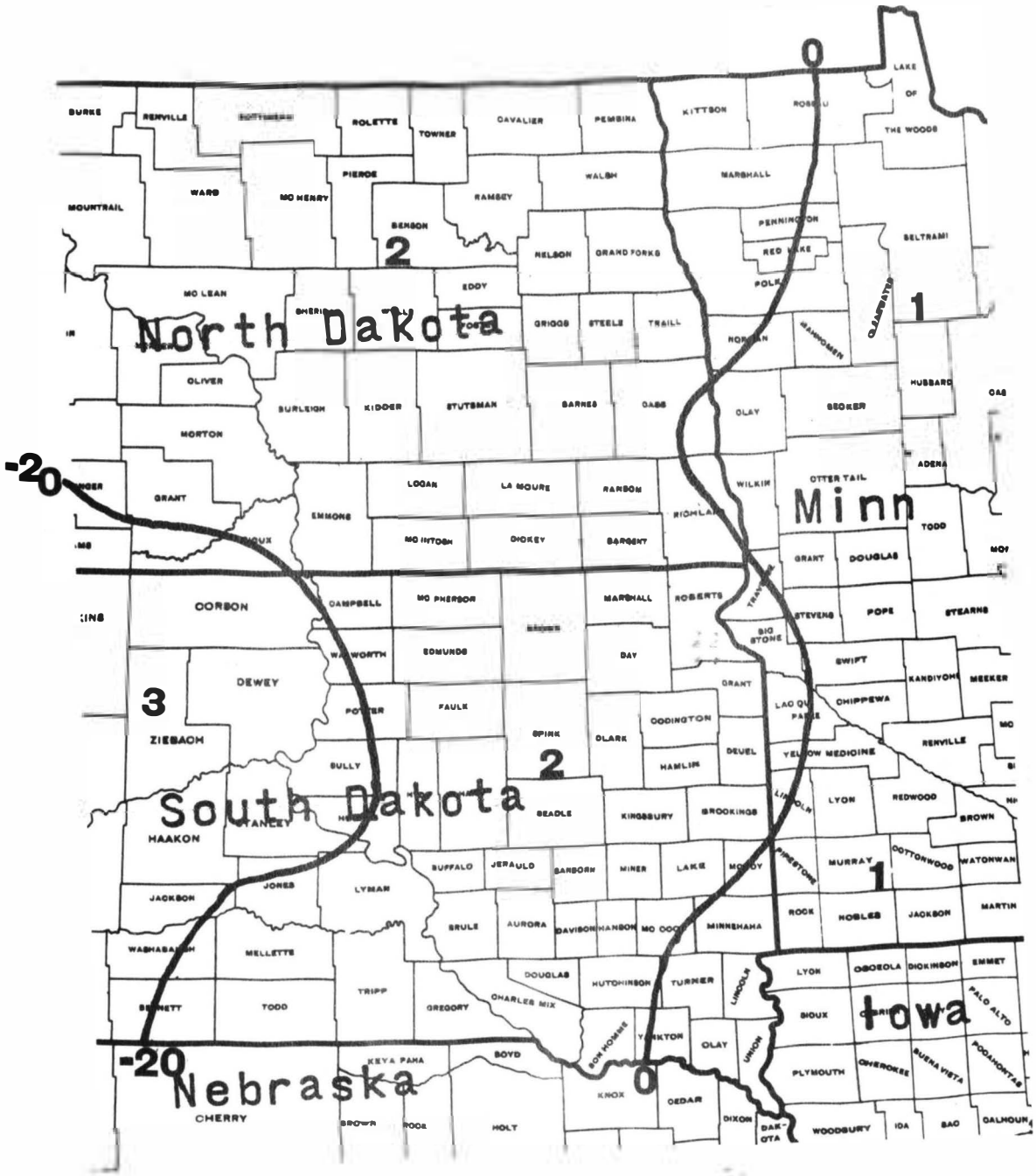

Figure 7. Moisture Regions of the United States

Moisture Deficiency Surplus Index
1- Moist subhumid
2 Dry subhumid
3- Semiarid

Source: Thornthwaite (36)

grasses and finally the short grasses become dominant (46). The dominant tall grass species were Big bluestem (Andropogon gerardi), Switch grass (Panicum virgatum) and Sloughgrass (Beckmania syzigachne). The mid-grasses were Little bluestem (Andropogon scoparius), Needle-and thread (Stipa comata) and Prairie dropseed (Sporobolus heterolepis). The short grasses were Blue grama (Bouteloua gracilis), Western wheatgrass (Agropyron smithii) and Buffalo grass (Buchloë dactyloides) (46, 1, 38).

METHODS OF INVESTIGATION

Field Methods

The field procedures used in this study consisted of three phases. First was the location of the study sites; second, the sampling of the study sites for laboratory analyses; and third, the description of the soil profiles sampled. Eleven sites were used in this study. Six were new site locations and five were previously sampled sites. Complete laboratory analyses were available on three of these old sites and partial analyses on two of the sites.

Location

The location of the six new sites was decided by making transects across the general areas of study. The prospective areas for new sites were McIntosh and Dickey Counties, North Dakota; McPherson and Brown Counties, South Dakota; and Ottertail and Grant Counties, Minnesota. The location of the two new sites in Minnesota was made by Dr. R. H. Rust of the University of Minnesota and Mr. Alex Robertson, State Soil Scientist for the Soil Conservation Service.

Brief descriptions were written of all checkpoints on the transects along the North and South Dakota border. Final selection of the new sites, two in North Dakota and two in South Dakota, was made from these descriptions. These transects were made in an attempt to find sites of typical well-drained soils of the areas developed from loam glacial till. Also the attempt was made to pair, in all observable respects, the two sites in North Dakota and the two sites in South Dakota.

A list of the eleven sites with their locations follows. For convenience in discussion, the sites will be referred to by number.

Site 1: Barnes County, North Dakota, No. S53-ND-2-1
Site 2: Steele County, North Dakota, No. S53-ND-46-1
Site 3: Spink County, South Dakota, No. S49-SD-58-11
Site 4: Brown County, South Dakota, No. S58-SD-6-1
Site 5: Brown County, South Dakota, No. S58-SD-6-2
Site 6: Dickey County, North Dakota, No. S58-ND-11-1
Site 7: Dickey County, North Dakota, No. S58-ND-11-2
Site 8: Grant County, South Dakota, No. S54-SD-26-1
Site 9: Grant County, South Dakota, No. S54-SD-26-2
Site 10: Grant County, Minnesota, No. S58-Minn-26-1
Site 11: Ottertail County, Minnesota, No. S58-Minn-56-1

Sampling

The sampling of all six new sites and the two old sites with partial analyses was done from pits. These pits were dug to a depth of four and one-half feet. The remaining six inches were sampled with an auger. Prior to excavation, the surface was covered with heavy paper to protect it from contamination. Bulk samples were taken from all delineated horizons for laboratory analyses. These samples were collected from the lowest horizon first and the surface horizon last in order to protect the surfaces of the other horizons from contamination.

Descriptions

After the pit was dug and prior to sampling, a field description of the sampling site was made. In this description notes were made of the following: number, kind, and thickness of horizons; structure; clearness and topography of horizon boundaries; mottling; lime; and decomposition of rocks and minerals present. Subsamples were taken for determining color, texture and consistence. Also peds (structural units) from

the B horizon were preserved in cotton for evaluating clay films.

Notes on the general description of each site were also made. These consisted of physiography, relief, slope aspect, erosion, estimated permeability, drainage, ground water, root distribution, salt or alkali, stoniness, parent material, vegetation and the exact location.

Furthermore, a tentative classification of the soil itself was made at the site.

The five previously sampled sites were also reopened and redescribed. These were all treated as above, except that no bulk samples were taken on the three sites with previous complete analyses. These five sites are located as follows: one in Spink County, and two in Grant County, South Dakota; one in Barnes County and one in Steele County, North Dakota.

Laboratory Methods

Prior to laboratory analysis all samples were air dried and ground to a size of less than 2 mm. All material larger than 2 mm. and smaller than 3/4 inch is reported as percent greater than 2 mm. The percentage is based on the total weight of the sample smaller than 3/4 inch. Material larger than 3/4 inch was discarded in the field.

The samples less than 2 mm. were mixed and quartered to assure uniformity in the samples used for analyses.

All the analyses for particle size distribution and organic carbon were made by the Soil Survey Laboratories at Mandan, North Dakota; Lincoln, Nebraska; or Beltsville, Maryland.

The pipette method was used for particle size distribution fol-

lowing the procedures described by Kilmer and Alexander (20), Kilmer and Mullins (21) and Olmstead, et al. (31). The organic carbon determinations were made by a modification of the Walkley - Black method as described by Peech, et al. (33).

Further, all analyses were made by the Soil Survey Laboratory at Mandan, North Dakota on sites 1, 2 and 3. These included cation exchange capacity by direct distillation of adsorbed ammonia as described by Peech, et al. (33). Extractable calcium was precipitated as calcium oxalate and extractable magnesium was precipitated as magnesium ammonium phosphate using procedures described by Peech, et al. (33).

Extractable hydrogen was determined by the triethanolamine method described by Peech, et al. (33). Extractable sodium and potassium in original extracts, and soluble sodium and potassium in the saturation extract was determined by a flame spectrophotometer.

Calcium carbonate equivalent was determined by measurement of carbon dioxide evolved after treatment with concentrated hydrochloric acid. Total nitrogen was determined by the modified method of the Association of Official Agricultural Chemists (3).

Some analyses were made by the Soils Laboratories, University of Minnesota, St. Paul, Minnesota of sites 10 and 11. These included calcium carbonate equivalent by titrating the unused acid following the method described by Richards (34); organic carbon by the dry combustion procedure described by Jackson (16); and cation exchange capacity by the silver titration procedure described by Holt (15).

Laboratory analyses of samples from sites 4, 5, 6, 7, 8, 9, 10 and 11 were made by the author. The pH of the saturated paste was determined by glass electrode.

The cation exchange capacity was determined by using a slight modification of the technique of cation replacement by sodium as described by Bower, et al. (8).

Extractable magnesium and calcium were determined on the extract by the Versenate procedure of Cheng and Bray (9).

Extractable hydrogen was determined by slightly modifying the barium acetate extraction method described by Parker (32) and modified to pH 8.1 by Mehlick (26).

Extractable sodium and potassium determinations were made of original extracts using the flame photometer internal standard method described by Jackson (17).

Saturation extract soluble sodium and potassium determinations were made on the extract using a flame photometer and the procedures described by Jackson (17) and Richards (34).

Electrical conductivity of the saturation extract was determined with a conductivity bridge.

The calcium carbonate equivalent was determined manometrically by the procedure described by Williams (50).

Total nitrogen was determined by using the modified Kjeldahl procedure described by Bal (5).

The exchangeable sodium percentages and carbon to nitrogen ratios were calculated.

All the laboratory results are reported on the oven dry basis and are the average of duplicate determinations.

FIELD RESULTS AND DISCUSSION

Field Results

A profile description is the primary tool used in studying soil morphology. When the data obtained by visually observing a soil profile are analyzed, some of the aspects of the formation become more apparent.

These field descriptions are the detailed written descriptions from the field notes and subsamples taken during sampling. The color designations are from the standard Munsell color chart and were obtained by reading the color of the subsamples under constant incandescent light in the office. Consistence was also determined from the same subsample. Textures and soil reaction are from laboratory analyses. The clay film notations are taken from the peds preserved during sampling. The clay films were observed for thickness and coverage under an eighteen power binocular microscope. The thickness was obtained by scratching the ped face with a broken pen point while observing it under the microscope.

Clay film thickness was divided into the following five categories: thin, moderately thin, moderate, moderately thick and thick. Thin clay films cannot be removed from the ped with a pen point; they form a noncontinuous light-reflecting surface. These films cannot be seen without magnification and will partially bridge the fine sand but none of the coarser sand. Moderate clay films can be removed from the ped with a pen point, although they rupture upon removal; they form a continuous light-reflecting surface. These films can generally be seen without magnification and will bridge the fine sand but only partially

bridge coarser sand. Thick clay films can readily be removed from the ped with a pen point although they also rupture upon removal; they form a continuous light-reflecting surface. These films can readily be seen without magnification; and will bridge all sand grains. The categories 'moderately thin' and 'moderately thick' are intergrades between the above categories.

Coverage of the peds by clay films was divided into the following three categories: very patchy, 0 to 40% covered; patchy, 40 to 90% covered; and continuous, 90 to 100% covered.

It must be remembered that these clay film designations are not absolute but relative among the eleven sites studied. Also they do not necessarily correspond to the criteria for division into coverage and thickness categories used by other workers in the field.

The descriptions themselves contain the usual information given in soil profile descriptions for morphology studies.

Site 1

Sample No.: S53-ND-2-1 Date: 9-5-58
Soil Type: Barnes loam. Area: Barnes Co. N. Dak.
Classification: Chernozem.
Location: 400' N, 90' W of SE cor. Sec. 20, Twp. 142 N, Rg. 56 W.
Vegetation: Cultivated for small grains.
Parent Material: Friable glacial till, Mankato substage.
Physiographic Position: Upland till plain on long convex slope, 50' E of crest.
Topography: Undulating to gently undulating, Relief 10' countrywise, 5' at site.
Slope: 3% to NE.
Erosion: Slight to moderate.
Drainage: Well.
Permeability: Moderate.
Moisture: Slightly moist to 24", moist.
Notes: Granite pebbles were decomposed. Shale particles were common from 31 to 60". This profile was sampled for laboratory analysis by W. M. Johnson (18) in 1953 but the gypsum horizons (C_{cs1} and C_{cs2}) noted by him were not noted when this description was written.

Soil Profile: Barnes loam.

A_{1p} 0-6" Black (10YR 2/1) loam, dark gray (10YR 4/1) when dry; crumbs have very dark gray to dark gray coats (10YR 3.5/1) when dry; weak medium crumb structure; hard to slightly hard when dry, friable to very friable when moist; numerous roots; noncalcareous; mildly alkaline; abrupt smooth boundary.

A_{12} 6-8" Black (10YR 2/1) loam, dark gray (10YR 4/1) when dry; peds have very dark gray coats (10YR 3/1) when dry; weak medium prismatic structure separating to weak fine to medium subangular blocky structure; hard when dry, friable to very friable when moist; moderate amount of roots; noncalcareous; mildly alkaline; clear wavy boundary.

B_2 8-16" Very dark gray (10YR 3/1) loam, dark gray (10YR 4/1) when dry; moderate medium prismatic structure separating to weak to moderate medium angular blocky structure; very hard when dry, friable when moist; moderate amount of roots; moderate patchy clay films on horizontal and vertical ped faces; noncalcareous; mildly alkaline; clear wavy boundary.

B_{3ca} 16-24" Light olive brown (2.5Y 5/4) loam, light gray

(2.5Y 7/2) when dry; weak medium to coarse prismatic structure separating to weak medium angular blocky structure; slightly hard to hard, dry, friable, moist; moderate amount of roots; moderately thick continuous clay films on horizontal ped faces, moderate patchy clay films on vertical ped faces; large amount of disseminated carbonates; moderately alkaline; gradual smooth boundary.

C_{ca} 24-31" Olive (5Y 5/3) loam, pale olive (5Y 6/3 when dry; weak very coarse prismatic structure; hard, dry, friable, moist; moderate amount of roots; common medium faint lime concretions; large amount of segregated carbonate; mildy alkaline; gradual smooth boundary.

C_1 31-47" Mottled olive (5Y 5/3) loam, pale olive (5Y 6/3) when dry; common fine prominent red (2.5YR 5/8 D) iron mottles; moderate horizontal blocky structure separating to weak fine to medium angular blocky structure; hard, dry, friable, moist; few roots; few pebbles; few medium distinct lime concretions; moderate amount of segregated carbonate; moderately alkaline; gradual smooth boundary.

C_2 47-60" Mottled olive to pale olive (5Y 5.5/3) loam, pale yellow (5Y 7/3) when dry; common fine prominent red (2.5YR 5/8 D) iron mottles; weak horizontal blocky structure; very hard, dry, friable, moist; few roots; few pebbles; few medium distinct lime concretions; moderate amount of segregated carbonate; moderately alkaline.

The following is a copy of Mr. Johnson's (18) description of the same profile:

A_{1p} 0-6" Very dark gray to black (10YR 3/1, dry; 2/1, moist) soft, friable, moderately very fine granular loam. The upper few inches that have been cultivated recently tend to be cloddy. Lower boundary is abrupt and smooth.

A_{12} 6-8" Very dark gray to black (10YR 3/1, dry; 2/1, moist) soft, friable, loam. Moderate medium blocky structure that breaks down to moderate fine granules. Lower boundary is clear and wavy -- it "tongues" down to the base of the B_2 horizon.

B_2 8-16" Grayish-brown to very dark grayish-brown (10YR 5/2.5, dry; 3.5/2.5, moist) soft, friable, loam. Structure is moderate medium prismatic; some of the prisms' faces have black coatings. Clear, slightly wavy lower boundary.

C_{ca} 16-24" Light-gray to brown (1Y 7.5/2.5, dry; 5.5/3, moist) with a very few tiny white specks. Very strongly calcareous, soft, friable, moderate very fine granular heavy loam. This horizon has a distinctly silty feel to it. Calcium carbonate is in disseminated form. Gradual, wavy lower boundary.

C_{cs1} 24-31" Light yellowish-brown to olive-brown (2.5Y 6.5/3, dry; 4/3 moist) soft, friable loam. There are many prominent white spots of gypsum crystals. Weak very fine irregular blocky structure. Strongly calcareous. Lower boundary is diffuse and slightly wavy.

C_{cs2} 31-39" Light yellowish-brown to olive-brown (2.5Y 6/3, dry; 4/4, moist) soft, friable loam, with a few medium and fine gray, white, and reddish-brown mottles. Weak coarse blocky structure. Strongly calcareous. Contains numberous "nests" of small gypsum crystals. Lower boundary is diffuse and slightly wavy.

C_1 39-47" Uniformly mottled light brownish-gray and light yellowish-brown (2.5Y 6/2 and 6/3, dry) to dark grayish-brown and olive-brown (2.5Y 4/2 and 4/3, moist) friable, weak coarse blocky loam till. Moderately calcareous. Has a few fine white spots of calcium carbonate and calcium sulphate crystals. Clear, wavy lower boundary.

C_2 47-60"+ Layered and mottled light yellowish-brown and light olive-brown (2.5Y 5.5/3 and 6/3, dry; 4/3 and 3/2, moist) parent till. The material is mixed and layered sandy clay loam, loam, and silt loam. Moderately calcareous. Crystalline gypsum concentrations in the lower 1 1/2". Soft when dry, friable when moist. Has a few fine mottles of red and yellowish red.

Site 2

Sample No.: S53-ND-46-1 Date: 9-5-58
Soil Type: Barnes clay loam. Area: Steele Co. N. Dak.
Classification: Chernozem.
Location: 270' N, 75' E of SW cor. Sec. 28, Twp. 144 N, Rg. 56 W.
Vegetation: Cultivated for small grains.
Parent Material: Friable glacial till, Mankato substage.
Physiographic Position: Upland till plain, near base of 150' long convex slope, slight drainage channel 75' E of site, flowing N.

Topography: Undulating to gently undulating, relief 20' countrywise, 10' at site.
Slope: 4% to E.
Erosion: Slight to moderate.
Drainage: Well.
Permeability: Moderate.
Moisture: Slightly moist to 36", moist.
Notes: Decomposition of granite minerals below 21". Organic tonguing to 14" causing the natural A_1 boundary to be a clear irregular boundary.

The B_{3ca} and C_{cal} horizons were combined when the laboratory analysis was made and described as C_{cal} on a previous description by W. M. Johnson (19).

Soil Profile: Barnes clay loam.

A_{1p}	0-6"	Black (10YR 2/1) clay loam, dark gray (10YR 4/1) when dry; crumbs have very dark gray coats (10YR 3/1) when dry; weak medium to fine crumb structure; slightly hard to hard when dry, friable to very friable when moist; numerous roots; noncalcareous; mildly alkaline; abrupt smooth boundary.
B_2	6-12"	Dark gray brown (10YR 4/2) loam, dark gray brown to gray brown (10YR 4.5/2) when dry; peds have very dark gray brown coats (10YR 3/2), dark gray brown (10YR 4/2) when dry; moderate medium prismatic structure, separating to moderate to strong medium angular blocky structure; very hard when dry, friable to firm when moist; many roots; moderately thick continuous clay films on vertical ped faces, moderate patchy clay films on horizontal ped faces; noncalcareous; mildly alkaline; clear irregular boundary due to organic tonguing.
B_{3ca}	12-14"	Dark gray brown (10YR 4/2) clay loam, gray brown (10YR 5/2) when dry; moderate medium prismatic structure separating to weak to moderate medium angular blocky structure; hard when dry; friable when moist; moderate amount of roots; few pebbles; common medium distinct lime concretions; thick continuous clay films on horizontal ped faces, moderate patchy clay films on vertical ped faces; moderate amount of segregated carbonates; moderately alkaline; clear smooth boundary.
C_{cal}	14-21"	Mottled light olive brown (2.5Y 5/4) clay loam, light yellowish-brown (2.5Y 6/4) when dry; few fine faint and distinct brownish-yellow (10YR 6/8 D) iron

		mottles; weak coarse prismatic structure separating to weak to moderate medium angular blocky structure; hard when dry, friable when moist; moderate amount of roots; moderate amount of pebbles; common medium distinct lime concretions; thick patchy clay films on horizontal ped faces; moderate patchy clay films on vertical ped faces; large amount of segregated carbonates; moderately alkaline; gradual wavy boundary.
C_{ca2}	21-36"	Mottled light olive brown (2.5Y 5/4) clay loam, light yellowish-brown (2.5Y 6/4) when dry; few fine prominent dark red (2.5YR 3/6 D) iron mottles; weak medium to coarse prismatic structure separating to weak medium angular blocky structure; very hard when dry, friable to firm when moist; moderate amount of roots; moderate amount of pebbles; common medium distinct lime concretions; moderate to large amount of segregated carbonate; strongly alkaline; gradual wavy boundary.
C_1	36-41"	Mottled light olive brown (2.5Y 5/4) clay loam, light yellowish-brown (2.5Y 6/4) when dry; common fine prominent dark red (2.5YR 3/6 D) iron mottles; weak to moderate horizontal blocky structure separating to weak fine to medium angular blocky structure; very hard when dry, friable when moist; few roots; moderate amount of pebbles; few fine faint lime concretions; moderate amount of segregated carbonate; moderately alkaline; gradual wavy boundary.
C_2	41-50"	Mottled light olive brown (2.5Y 5/4) loam, light yellowish-brown (2.5Y 6/4) when dry; common medium prominent dark red (2.5YR 3/6 D) iron mottles; weak horizontal blocky structure; very hard when dry, firm when moist; few roots; moderate amount of pebbles; common fine distinct lime concretions; common fine faint threads of segregated lime; large amount of disseminated carbonate; moderately alkaline; gradual wavy boundary.
C_3	50-60"	Mottled light olive brown (2.5Y 5/4) loam, light yellowish-brown (2.5Y 6/4) when dry; common fine to medium prominent dark red (2.5YR 3/6 D) iron mottles; weak horizontal blocky structure; very hard when dry, friable to firm when moist; few roots; moderate amount of pebbles; common medium distinct threads of segregated lime; moderate to large amount of disseminated carbonate; moderately alkaline.

Site 3

Sample No.: S49-SD-58-11 Date: June 9, 1958
Soil Type: Houdek loam. Area: Spink Co. S. Dak.
Classification: Chernozem intergrading to Chestnut.
Location: 400' W, 200' N of SE corner, Sec. 10, Twp. 119 N, Rg. 65 W.
Vegetation: Native grasses, Blue grama, Stipa, Brome and Western wheat grass.
Parent Material: Friable glacial till, Mankato substage.
Physiographic Position: Upland till plain, near crest on a long convex slope.
Topography: Gently undulating, Relief 10' countrywise, 2' at site.
Slope: 2% to W.
Erosion: None to slight.
Drainage: Well.
Permeability: Moderate.
Moisture: Dry to 40", moist.
Notes: Granite minerals were decomposed. Shale fragments from 14" on down. Organic tonguing to 14". The A_1 and AB; B_{21} and B_{22}; B_{3ca2}, C_{ca} and C_1 horizons were combined for laboratory analysis and called respectively A_1, B_2 and C_{ca} on a previous description by C. A. Mogen (27).

Soil Profile: Houdek loam.

A_1 0-3" Black (10YR 2/1) loam, very dark gray brown to dark gray brown (10YR 3.5/2) when dry; moderate fine granular structure; slightly hard when dry, friable when moist; numerous roots; noncalcareous; medium acid; gradual smooth boundary.

AB 3-6.5" Very dark brown (10YR 2/2) loam, dark gray brown (10YR 4/2) when dry; peds have black coats (10YR 2/1), very dark gray brown (10YR 3/2) when dry; weak to moderate medium prismatic structure, separating to moderate fine to medium subangular blocky structure; slightly hard when dry, friable when moist; numerous roots; noncalcareous; medium acid; clear wavy boundary.

B_{21} 6.5-11.5" Very dark gray brown (10YR 3/2) clay loam, gray brown (10YR 5/2) when dry; peds have very dark brown coats (10YR 2/2), dark gray brown to gray brown (10YR 4.5/2) when dry; moderate fine to medium prismatic structure, separating to moderate medium angular blocky structure; slightly hard when dry, friable to firm when moist; many roots; moderately thick continuous clay films on both horizontal and vertical ped faces; noncalcareous; neutral; clear wavy boundary.

B_{22}	11.5-14"	Dark brown to brown (10YR 4/3) clay loam, dark gray brown to gray brown (10YR 4.5/2) when dry; peds have very dark gray brown coats (10YR 3/2), dark brown to brown (10YR 4/3) when dry; moderate medium prismatic structure, separating to moderate to strong fine to medium angular blocky structure, in turn separating to medium fine angular blocky structure; hard when dry, friable when moist; many roots; moderate continuous clay films on horizontal ped faces, moderate patchy clay films on vertical ped faces; noncalcareous; neutral; clear smooth boundary.
B_{3ca1}	14-19"	Olive brown (2.5Y 4/4) clay loam, light olive brown to light yellowish brown (2.5Y 5.5/4) when dry; moderate to strong medium prismatic structure, separating to moderate medium angular blocky structure; hard when dry, friable when moist; many roots; few pebbles; moderately thick continuous clay films on horizontal ped faces, moderate continuous clay films on vertical ped faces; common fine distinct lime segregations as threads; large amount of segregated carbonate; neutral; clear smooth boundary.
B_{3ca2}	19-26"	Mottled light olive brown (2.5Y 5/4) clay loam, pale yellow (2.5Y 7/4) when dry; peds have olive brown coats (2.5Y 4/4), light olive brown to light yellowish brown (2.5Y 5.5/4) when dry; few fine faint and distinct brownish yellow (10YR 6/8 D) iron mottles; weak to moderate very coarse prismatic structure, separating to weak to moderate fine prismatic structure, in turn separating to weak medium angular blocky structure; slightly hard when dry, friable to firm when moist; moderate amount of roots; few pebbles; common medium distinct lime concretions; moderately thick continuous clay films on both horizontal and vertical ped faces; large amount of segregated carbonate; mildly alkaline; clear wavy boundary.
C_{ca}	26-35"	Mottled light olive brown (2.5Y 5/4) clay loam, light yellowish brown (2.5Y 6/4) when dry; few fine prominent dark red (2.5YR 3/6 D) iron mottles; weak very coarse prismatic structure, separating to weak fine prismatic structure, in turn separating to weak fine angular blocky structure; very hard when dry, firm when moist; few roots; moderate amount of pebbles; common medium distinct lime concretions; large amount of segregated carbonate; mildly alkaline; clear smooth boundary.

C_1 35-41" Mottled light olive brown (2.5Y 5/4) loam, pale yellow (2.5Y 7/4) when dry; common fine prominent dark red (2.5YR 3/6 D) iron mottles; weak medium blocky structure; hard when dry, friable to firm when moist; few roots; moderate amount of pebbles; few to common medium distinct lime concretions; moderate amount of disseminated carbonate; mildly alkaline; gradual smooth boundary.

C_2 41-60" Mottled olive brown to light olive brown (2.5Y 4.5/4) loam, pale yellow (2.5Y 7/4) when dry; common fine to medium prominent dark red (2.5YR 3/6 D) iron mottles; few fine distinct black (10YR 2/1 D) manganese mottles; weak horizontal blocky structure; very hard when dry, friable to firm when moist; few roots; moderate amount of pebbles; few to common medium faint lime concretions; moderate amount of disseminated carbonate; moderately alkaline.

The following is a copy of Mr. Mogen's (27) description of the same profile:

A_1 0-7" Dark grayish-brown to very dark brown (10YR 4/1.5 to 2/1.5 moist) noncalcareous loam; soft moderately developed fine granular structure; very friable when moist. This grades into

B_2 7-14" Brown to very dark grayish-brown (10YR 5/3 to 3/2, moist) noncalcareous clay loam; slightly hard, strongly developed fine and medium prisms separating out into strongly developed fine blocks; friable when moist. This grades into

B_3 14-18" Light yellowish-brown to olive-brown (2.5Y 6/3 to 4/3, moist) noncalcareous clay loam; slightly hard moderately developed medium sized prisms separating out into moderately developed fine blocks; friable when moist. This changes clearly into

C_{ca} 18-42" Pale-yellow mottled with white and light olive-brown mottled with light-gray (2.5Y 7/3 and 8/1 to 5/3 and 7/1, moist) strongly calcareous clay loam with a moderate amount of segregated lime; slightly hard massive structure, friable when moist.

C_1 42-53" Pale-yellow and light gray to light olive-brown and light gray (2.5Y 7/4 and 7/1 to 5/3 and 6/1, moist) moderately calcareous loam with a slight amount of segregated lime; slightly hard massive structure, very friable when moist. This grades into

C_2 53-65" Colors as in the horizon above in moderately calcareous loam; slightly hard massive structure; very friable when moist.

Site 4

Sample No.: S58-SD-6-1 Date: 8-12-58
Soil Type: Houdek loam. Area: Brown Co. S. Dak.
Classification: Chernozem intergrading to Chestnut.
Location: 430' SSE on line between approach (530' W of N 1/4 cor.) and corner post in center of Section. Sec. 36, Twp. 128 N, Rg. 65 W.
Vegetation: Native grasses, Redtop, Western wheat grass, Sweet clover, Stipa, Gumweed, Blue grama, and Sunflower.
Parent Material: Friable glacial till, Mankato substage.
Physiographic Position: Upland till plain at crest of knoll, nearly level to W, dropping to a slough to SE.
Topography: Undulating, Relief 25' countrywise, nearly level at site.
Slope: 2% to E.
Erosion: None to slight.
Drainage: Well.
Permeability: Moderate.
Moisture: Slightly moist to 30", moist.
Note: Granite minerals were decomposed. The C horizon had some lignite fragments.

Soil Profile: Houdek loam.

A_{11} 0-2" Black (10YR 2/1) loam, very dark gray (10YR 3/1) when dry; weak fine crumb structure; slightly hard when dry, friable when moist; numerous roots; noncalcareous; neutral; clear smooth boundary.

A_{12} 2-4" Black (10YR 2/1) loam, very dark gray brown (10YR 3/2) when dry; weak medium prismatic structure, separating to moderate fine to medium angular blocky structure; slightly hard when dry, very friable when moist; many roots; noncalcareous; neutral; clear wavy boundary.

B_{21} 4-9" Brown to dark brown (10YR 4/3) clay loam to loam, brown (10YR 5/3) when dry; peds have dark brown coats (10YR 3/3), brown (10YR 4.5/3) when dry; moderate medium prismatic structure separating to moderate medium angular blocky structure; hard to very hard when dry, friable when moist; many roots; moderate patchy clay films on vertical ped faces, moderate continuous clay films on horizontal ped faces; noncalcareous; neutral; clear smooth boundary.

B_{22} 9-13" Dark gray brown (10YR 4/2) loam, gray brown to dark gray brown (10YR 4.5/2) when dry; peds have very dark gray brown coats (10YR 3/2), dark gray brown (10YR 4/2) when dry; moderate medium prismatic structure separating to moderate medium angular blocky structure; slightly hard to hard when dry, friable when moist; many roots; moderate patchy clay films on vertical ped faces, moderate continuous clay films on horizontal ped faces; non-calcareous; neutral; clear smooth boundary.

B_{3ca} 13-17" Olive brown (2.5Y 4/4) loam, light olive brown (2.5Y 5/4) when dry; moderate medium prismatic structure separating to moderate medium to coarse angular blocky structure; very hard when dry, firm to friable when moist; moderate amount of roots; few pebbles; few fine faint lime segregations, slight amount of disseminated carbonates; strongly alkaline; clear smooth boundary.

C_{ca1} 17-23" Light olive brown (2.5Y 5/4) loam, light yellowish brown (2.5Y 6/4) when dry; peds have olive brown coats (2.5Y 4/4), light olive brown (2.5Y 5.5/4) when dry; weak coarse prismatic structure separating to weak coarse angular blocky structure; very hard when dry, friable when moist; moderate amount of roots; moderate amount of pebbles; common fine distinct soft lime concretions; moderate amount of segregated carbonates; strongly alkaline; clear smooth boundary.

C_{ca2} 23-30" Mottled light olive brown (2.5Y 5/4) clay loam, light yellowish brown (2.5Y 6/4) when dry; few fine distinct dark red (2.5YR 3/6 D) iron mottles; weak very coarse prismatic structure separating to weak very coarse angular blocky structure; very hard when dry, friable when moist; few roots; moderate amount of pebbles; common medium distinct hard lime concretions; lime cemented horizon; large amount of segregated carbonates; strongly alkaline; clear smooth boundary.

C_1 30-48" Mottled light olive brown to olive brown (2.5Y 4.5/4) loam, light yellowish brown (2.5Y 6/4) when dry; few fine distinct dark red (2.5YR 3/6 D) iron mottles; very weak horizontal blocky structure; very hard when dry, friable when moist; few roots; moderate amount of pebbles; common medium distinct soft lime concretions; moderate amount of carbonates segregated in threads; strongly alkaline; gradual diffuse boundary.

C_2 48-60" Mottled light olive brown to olive brown (2.5Y 4.5/4) loam, light yellowish brown (2.5Y 6/4) when dry; common medium distinct dark red (2.5YR 3/6 D) iron mottles, few medium faint light gray (10YR 7/2 D) mottles; very weak horizontal blocky structure; very hard when dry; friable when moist; few roots; moderate amount of pebbles; few fine faint soft lime concretions; slight to moderate amount of carbonates segregated in threads; strongly alkaline.

Site 5

Sample No.: S58-SD-6-2 Date: 8-12-58
Soil Type: Houdek loam. Area: Brown Co. S. Dak.
Classification: Chernozem intergrading to Chestnut.
Location: 100' S of N 1/4 cor. Sec. 19, Twp. 128 N, Rg. 64 W.
Vegetation: Native grasses, Blue grama, Western wheat grass, Green needle, and Needle-and-thread grass present but predominately Gumweed has invaded.
Parent Material: Friable glacial till, Mankato substage.
Physiographic Position: Upland till plain, 75' N of crest of knoll, small channel 400' to N.
Topography: Gently undulating, Relief 15' countrywise, sloping at site.
Slope: 3% to N.
Erosion: None to slight.
Drainage: Well.
Permeability: Moderate.
Moisture: Dry to 31", moist.
Note: All granite minerals were decomposed. The C horizon had some lignite fragments.

Soil Profile: Houdek loam.

A_{11} 0-2" Black (10YR 2/1) loam, dark gray (10YR 4/1) when dry; crumbs have very dark gray to dark gray coats (10YR 3.5/1) when dry; weak medium crumb structure; slightly hard when dry, very friable when moist; numerous roots; noncalcareous; neutral; clear smooth boundary.

A_{12} 2-4" Very dark brown (10YR 2/2) loam, very dark gray brown to dark brown (10YR 3.5/2) when dry; peds have black coats (10YR 2/1), very dark gray brown (10YR 3/2) when dry, weak to moderate medium prismatic structure separating to moderate medium crumb structure; slightly hard to hard when dry, very friable when moist; many roots; noncalcareous; neutral; clear wavy boundary.

B_{21} 4-8" Dark brown to brown (10YR 4/3) clay loam, brown (10YR 4.5/3) when dry; peds have dark brown coats (10YR 3/3), dark brown to brown (10YR 4/3) when dry; moderate to strong medium prismatic structure, separating to moderate fine to medium angular blocky structure; very hard when dry, friable to very friable when moist; many roots; thin patchy clay films on vertical and horizontal ped faces; noncalcareous; neutral; clear smooth boundary.

B_{22} 8-12" Dark brown to brown (10YR 4/3) clay loam, brown (10YR 5/3) when dry; peds have dark brown coats (10YR 3/3), brown (10YR 4.5/3) when dry; moderate medium prismatic structure, separating to moderate medium angular blocky structure; very hard when dry, friable when moist; many roots; moderate continuous clay films on horizontal and vertical ped faces; noncalcareous; mildly alkaline; clear smooth boundary.

B_{3cs} 12-16" Mottled olive brown (2.5Y 4/4) clay loam, light olive brown (2.5Y 5/4) when dry; few fine faint brownish yellow (10YR 6/8 D) iron mottles; moderate medium to coarse prismatic structure, separating to moderate medium angular blocky structure; slightly hard when dry; friable when moist; moderate amount of roots; few pebbles; few medium distinct lime concretions; moderate amount of disseminated carbonates; strongly alkaline; clear wavy boundary.

C_{ca1} 16-24" Mottled olive brown to light olive brown (2.5Y 4.5/4) clay loam; light yellowish brown (2.5Y 6/4) when dry; few fine distinct dark red (2.5YR 3/6 D) iron mottles; weak coarse prismatic structure, separating to weak to moderate coarse angular blocky structure; very hard when dry, firm when moist; moderate amount of roots; moderate amount of pebbles; common fine distinct soft lime concretions; large amount of disseminated carbonates; strongly alkaline; gradual wavy boundary.

C_{ca2} 24-31" Mottled light olive brown (2.5Y 5/4) clay loam, pale yellow (2.5Y 7/4) when dry; few fine distinct dark red (2.5YR 3/6 D) iron mottles; weak very coarse prismatic structure, separating to weak coarse angular blocky structure; hard to very hard when dry, firm when moist; moderate amount of roots; moderate amount of pebbles; common medium distinct hard lime concretions; lime cemented horizon, large amount of disseminated carbonates; strongly alkaline; clear smooth boundary.

C_1 31-46" Mottled olive brown to light olive brown (2.5Y 4.5/4) clay loam to loam, light yellowish brown (2.5Y 6/4) when dry; few fine prominent dark red (2.5YR 3/6 D) iron mottles; weak horizontal blocky structure; very hard when dry, friable to firm when moist; few roots; moderate amount of pebbles; moderate amount of disseminated carbonates; strongly alkaline; gradual wavy boundary.

C_2 46-60" Mottled olive brown to light olive brown (2.5Y 4.5/4) loam, light yellowish brown (2.5Y 6/4) when dry; few fine prominent dark red (2.5YR 3/6 D) iron mottles, few fine distinct black (10YR 2/1) manganese mottles; weak horizontal blocky structure; very hard when dry, firm when moist; few roots; moderate amount of pebbles; common medium faint soft lime segregations; moderate amount of disseminated carbonates; strongly alkaline.

Site 6

Sample No.: S58-ND-11-1 Date: 8-11-58
Soil Type: Barnes (like) loam. Area: Dickey Co. N. Dak.
Classification: Chernozem intergrading to Chestnut?
Location: 530' S, 530' W of E 1/4 cor. Sec. 3, Twp. 129 N, Rg. 62 W.
Vegetation: Native grasses, Western wheat grass, Blue grama, Fringed sagewart, False plantain.
Parent Material: Friable glacial till, Mankato substage.
Physiographic Position: Upland till plain, small slough 200' to N.
Topography: Gently undulating, Relief 10' countrywise, nearly level at site.
Slope: 2% to N.
Erosion: None to slight.
Drainage: Well.
Permeability: Moderate.
Moisture: Dry to 18", moist.
Note: All granite minerals were decomposed. The C horizon had some lignite fragments. Organic tonguing to 18". Badger working in site vicinity.

Soil Profile: Barnes (like) loam.

A_{11} 0-2" Black (10YR 2/1) loam, dark gray (10YR 4/1) when dry; crumbs have very dark gray coats (10YR 3/1 D); weak medium to fine crumb structure; hard to slightly hard when dry, friable to very friable when moist; numerous roots; noncalcareous; neutral; clear smooth boundary.

A_{12}	2-5"	Black (10YR 2/1) loam, very dark gray brown to dark gray brown (10YR 3.5/2) when dry; peds have very dark gray brown coats (10YR 3/2 D); weak medium prismatic structure, separating to moderate medium to fine angular blocky structure, about 20% weak medium to fine crumb structure unincorporated in peds; slightly hard when dry, very friable to friable when moist; many roots; noncalcareous; neutral; clear wavy boundary.
B_{21}	5-9"	Dark brown to brown (10YR 4/3) loam, brown (10YR 5/3) when dry; peds have dark brown coats (10YR 3/3), dark brown to brown (10YR 4/3) when dry; moderate medium prismatic structure, separating to moderate fine to medium angular blocky structure, about 10% weak medium crumb structure unincorporated in peds; very hard when dry, friable to very friable when moist; moderate amount of roots; moderate patchy clay films on vertical ped faces, thin to moderate patchy clay films on horizontal ped faces; noncalcareous; mildly alkaline; clear wavy boundary.
B_{22}	9-14"	Dark brown to brown (10YR 4/3) loam, brown (10YR 5/3) when dry; peds have dark brown coats (10YR 3/3), dark brown to brown (10YR 4/3) when dry; moderate medium prismatic structure, separating to weak fine prismatic structure, in turn separating to moderate fine to medium angular blocky structure; very hard when dry, friable when moist; moderate amount of roots; few pebbles; moderate patchy clay films on vertical ped faces, moderate continuous clay films on horizontal ped faces; noncalcareous; moderately alkaline; clear wavy boundary.
B_{3ca}	14-17"	Olive brown (2.5Y 4/4) loam, light olive brown (2.5Y 5/4) when dry; weak to moderate medium prismatic structure, separating to moderate medium angular blocky structure; hard when dry, friable when moist; moderate amount of roots; few pebbles; common medium distinct soft lime concretions; moderate amount of segregated carbonates; strongly alkaline; clear wavy boundary.
C_{ca1}	17-24"	Mottled light olive brown (2.5Y 5/4) loam, light yellowish brown (2.5Y 6/4) when dry; few fine distinct brownish yellow (10YR 6/8) iron mottles; weak coarse prismatic structure, separating to weak coarse angular blocky structure; very hard to hard when dry, friable when moist; few roots; moderate amount of pebbles; common medium distinct soft lime concretions; large amount of carbonates segregated

in threads and nodules; strongly alkaline; gradual smooth boundary.

C_{ca2} 24-30" Mottled light olive brown (2.5Y 5/4) loam, light yellowish brown (2.5Y 6/4) when dry; few fine distinct dark red (2.5YR 3/6) iron mottles; very weak coarse prismatic structure, separating to weak coarse angular blocky structure; hard when dry, firm when moist; few roots; moderate amount of pebbles; common fine distinct hard lime concretions; cemented horizon; large amount of disseminated carbonate; strongly alkaline; clear smooth boundary.

C_{cs} 30-46" Mottled olive brown (2.5Y 4/4) loam, light yellowish brown (2.5Y 5/4) when dry; common fine prominent dark red (2.5YR 3/6) iron mottles; very weak coarse angular blocky structure; hard when dry, friable when moist; few roots; moderate amount of pebbles; common medium distinct soft lime concretions; moderate amount of disseminated carbonates; common fine gypsum crystals; strongly alkaline; gradual smooth boundary.

C_1 46-60" Mottled olive brown (2.5Y 4/4) loam, light yellowish brown (2.5Y 5/4) when moist; common fine and medium prominent dark red (2.5YR 3/6) iron mottles; common fine distinct black (10YR 2/1) manganese mottles; weak horizontal blocky structure; very hard when dry, friable to firm when moist; few roots; moderate amount of pebbles; slight to moderate amount of disseminated carbonates; strongly alkaline.

Site 7

Sample No.: S58-ND-11-2 **Date:** 8-13-58
Soil Type: Barnes (like) loam. **Area:** Dickey Co. N. Dak.
Classification: Chernozem intergrading to Chestnut?
Location: 435' W, 600' N of S 1/4 cor. Sec. 20, Twp. 130 N, Rg. 62 W.
Vegetation: Native grasses, Western wheat grass, Blue grama, and Sunflower are present but Gumweed has invaded to almost 100% coverage.
Parent Material: Friable glacial till, Mankato substage.
Physiographic Position: Upland till plain, deep drainage channel (slough) 100' to WNW, site on crest of ridge following channel.
Topography: Gently undulating, Relief 20' countrywise nearly level at site.
Slope: 3% to SSW.
Erosion: Slight.
Drainage: Well.

Permeability: Moderate.
Moisture: Dry to 32", moist.
Notes: All granite minerals were decomposed. Sandstones well weathered, held together by Ca CO_3. The C horizon had some lignite fragments. Organic tonguing to 18".

Soil Profile: Barnes (like) loam.

A_{11} 0-2" Black (10YR 2/1) loam, very dark gray (10YR 3/1) when dry; crumbs have very dark gray brown coats (10YR 3/2 D); weak medium crumb structure; hard when dry, friable when moist; numerous roots; noncalcareous; moderately alkaline; clear smooth boundary.

A_{12} 2-4" Black (10YR 2/1) loam, very dark gray to dark gray (10YR 3.5/1) when dry; peds have very dark gray coats (10YR 3/1) when dry; weak medium prismatic structure, separating to moderate medium angular blocky structure; hard when dry, friable when moist; many roots; noncalcareous; moderately alkaline; clear wavy boundary.

B_{21} 4-8" Dark brown (10YR 3.5/3) loam, dark brown to brown (10YR 4/3) when dry; peds have very dark gray brown coats (10YR 3/2), dark gray brown (10YR 4/2) when dry; moderate to strong medium prismatic structure, separating to moderate medium angular blocky structure; very hard when dry, friable to firm when moist; many roots; moderate patchy clay films on both vertical and horizontal ped faces; noncalcareous; moderately alkaline; clear wavy boundary.

B_{22} 8-14" Dark brown to brown (10YR 4/3) loam, brown (10YR 5/3) when dry; peds have dark brown coats (10YR 3/3), dark brown to brown (10YR 4/3) when dry; moderate medium prismatic structure, separating to moderate medium angular blocky structure; very hard when dry, firm to friable when moist; many roots; moderate continuous clay films on both vertical and horizontal ped faces; noncalcareous; moderately alkaline; clear wavy boundary.

B_{3ca} 14-18" Olive brown (2.5Y 4/4) loam, light olive brown to light yellowish brown (2.5Y 5.5/4) when dry; moderate medium prismatic structure, separating to moderate medium angular blocky structure; slightly hard when dry, friable to firm when moist; moderate amount of roots; few pebbles; few fine distinct threads of segregated lime; slight amount of disseminated carbonates; strongly alkaline; clear wavy boundary.

C_{ca1}	18-26"	Mottled olive brown to light olive brown (2.5Y 4.5/4) loam, light yellowish brown (2.5Y 6/4) when dry; few fine distinct brownish yellow (10YR 6/8 D) iron mottles; weak coarse prismatic structure separating to weak coarse angular blocky structure; very hard when dry; friable to firm when moist; moderate amount of roots; moderate amount of pebbles; common medium distinct soft lime concretions; large amount of disseminated carbonates; strongly alkaline; clear wavy boundary.
C_{ca2}	26-32"	Mottled olive brown (2.5Y 4/4) loam, light olive brown (2.5Y 5/4) when dry; few fine distinct dark red (2.5YR 3/6 D) iron mottles; weak very coarse prismatic structure, separating to weak coarse angular blocky structure; very hard when dry, firm when moist; moderate amount of roots; moderate amount of pebbles; common medium distinct hard lime concretions; cemented horizon; large amount of disseminated carbonates; strongly alkaline; clear smooth boundary.
C_1	32-45"	Mottled light olive brown (2.5Y 5/4) loam, light yellowish brown (2.5Y 6/4) when dry; common medium prominent dark red (2.5YR 3/6 D) iron mottles; weak horizontal blocky structure; very hard when dry, firm to friable when moist; few roots; moderate amount of pebbles; few fine faint threads of segregated lime; moderate amount of disseminated carbonates; strongly alkaline; gradual smooth boundary.
C_{cs}	45-60"	Mottled light olive brown (2.5Y 5/4) loam, light yellowish brown (2.5Y 6/4) when dry; many medium prominent dark red (2.5YR 3/6 D) iron mottles; few fine distinct black (10YR 2/1 D) manganese mottles; weak horizontal blocky structure; very hard when dry, firm when moist; few roots; moderate amount of pebbles; few fine faint threads of segregated lime; slight to moderate amount of disseminated carbonates; common medium gypsum crystals; strongly alkaline.

Site 8

Sample No.: S54-SD-26-1 Date: Oct. 4, 1958
Soil type: Barnes clay loam. Area: Grant Co. S. Dak.
Classification: Chernozem.
Location: 210' W, 60' N of S 1/4 cor. Sec. 12, Twp. 121 N, Rg. 48 W.
Vegetation: Native grasses, Big bluestem, Western wheat grass, Brome, Silver sage, Stipa, Lupine and rosebushes.
Parent Material: Friable glacial till, Mankato substage.

Physiographic position: Upland till plain, on crest of ridge between North Fork Whetstone River and a short drainage tributary to river. Site 50' W of crest of ridge. Slopes 8% into tributary 100' to the west.
Topography: Undulating, relief 25' countrywise (to river), 3' at site.
Slope: 4% to W.
Erosion: Slight.
Drainage: Well.
Permeability: Moderate.
Moisture: Slightly moist to 24", moist.
Notes: Decomposed granite pebbles from 36". Organic tonguing to 16".

Soil Profile: Barnes clay loam.

A_{11} 0-2" Black (10YR 2/1) clay loam, very dark gray to dark gray (10YR 3.5/1) when dry; crumbs have very dark gray coats (10YR 3/1 D); weak medium to fine crumb structure; slightly hard when dry, friable when moist; numerous roots; noncalcareous; neutral; clear smooth boundary.

A_{12} 2-5" Black (10YR 2/1) loam, very dark gray (10YR 3/1) when dry; weak medium prismatic structure, separating to weak to moderate fine to medium angular blocky structure; hard when dry, friable when moist; many roots; noncalcareous; neutral; gradual smooth boundary.

AB 5-7.5" Very dark brown (10YR 2/2) loam, very dark gray (10YR 3/1) when dry; peds have black coats (10YR 2/1), very dark gray to dark gray when dry; weak medium prismatic structure, separating to moderate medium angular blocky structure; hard to slightly hard when dry, friable when moist; many roots; moderately thick continuous clay films on horizontal ped faces, moderate patchy on vertical ped faces; noncalcareous; neutral; clear wavy boundary.

B_2 7.5-16" Dark brown (10YR 3.5/3) loam, brown (10YR 5/3) when dry; peds have dark brown coats (10YR 3/3), brown (10YR 5/3) when dry; moderate medium prismatic structure, separating to moderate medium to coarse angular blocky structure; very hard when dry, firm when moist; moderate amount of roots; few pebbles; thick continuous clay films on horizontal ped faces, moderately thick continuous clay films on vertical ped faces; noncalcareous; neutral; abrupt wavy boundary.

C_{ca1} 16-24" Mottled olive brown (2.5Y 4/4) loam, light yellowish brown (2.5Y 6/4) when dry; few fine prominent dark red (2.5YR 3/6 D) iron mottles; weak medium to coarse

prismatic structure, separating to weak medium platy structure, in turn separating to weak to moderate medium angular blocky structure; hard when dry, friable when moist; moderate amount of roots; moderate amount of lime coated pebbles; common medium distinct lime concretions; large amount of carbonate segregated in threads; mildly alkaline; clear smooth boundary.

C_{ca2}	24-36"	Mottled light olive brown (2.5Y 5/4) loam, pale yellow (2.5Y 8/4) when dry; few fine prominent dark red (2.5YR 3/6 D) iron mottles; weak medium to coarse angular blocky structure; hard when dry, firm when moist; moderate amount of roots; moderate amount of lime coated pebbles; many medium faint lime concretions; large amount of carbonate segregated in threads; mildly alkaline; clear smooth boundary.
C_1	36-48"	Mottled light olive brown (2.5Y 5/4) loam, pale yellow (2.5Y 7/4) when dry; few medium prominent dark red (2.5YR 3/6 D) iron mottles; weak horizontal blocky structure; very hard when dry, friable to firm when moist; few roots; moderate amount of lime coated pebbles; common medium faint lime concretions; large amount of disseminated carbonate; moderately alkaline; gradual smooth boundary.
C_2	48-60"	Mottled light olive brown (2.5Y 5/4) loam, light yellowish brown (2.5Y 6/4) when dry; many medium prominent dark red (2.5YR 3/6 D) iron mottles; weak horizontal blocky structure; very hard when dry, friable to firm when moist; few roots; moderate amount of lime coated pebbles; common medium faint lime concretions; slight to moderate amount of disseminated carbonate; moderately alkaline.

Site 9

Sample No.: S54-SD-26-2 Date: Oct. 4, 1958
Soil Type: Barnes loam. Area: Grant Co. S. Dak.
Classification: Chernozem.
Location: 22/100 mi. E, 300' S of N 1/4 cor. Sec. 32, Twp. 121 N, Rg. 47 W.
Vegetation: Native grasses, Stipa, Bluegrass, Silver sage.
Parent Material: Friable glacial till, Mankato substage.
Physiographic Position: Upland till plain, on slope to draw leading to the South Fork of Whetstone River, 50' E of crest of draw on long convex slope.
Topography: Undulating, Relief 50' countrywise (to river), 3' at site.
Slope: 3% WSW.

Erosion: Slight.
Drainage: Well.
Permeability: Moderate.
Moisture: Slightly moist to 24", moist.
Notes: Decomposed granite from 34". B_{3ca1} and B_{3ca2} horizons were combined for laboratory analysis by C. A. Mogen (29).

Soil Profile: Barnes loam.

A_{11} 0-2" Black (10YR 2/1) loam, very dark brown (10YR 2/2) when dry; weak medium to fine crumb structure; slightly hard when dry, friable when moist; numerous roots; noncalcareous; slightly acid; clear smooth boundary.

A_{12} 2-5" Black to very dark brown (10YR 2/1.5) loam, very dark gray brown (10YR 3/2) when dry; blocks have black coats (10YR 2/1), very dark brown (10YR 2/2) when dry; weak medium angular blocky structure, separating to weak medium to fine crumb structure; hard to slightly hard when dry, friable when moist; many roots; noncalcareous; slightly acid; clear wavy boundary.

AB 5-7.5" Very dark brown (10YR 2/2) sandy loam, brown (10YR 4.5/3) when dry; peds have black coats (10YR 2/1), very dark gray brown (10YR 3/2) when dry; weak to moderate medium prismatic structure, separating to weak medium angular blocky structure; slightly hard when dry, friable when moist; many roots; thin patchy clay films on horizontal ped faces, moderately thin patchy clay films on vertical ped faces; noncalcareous; slightly acid; clear smooth boundary.

B_2 7.5-15" Dark brown to brown (10YR 4/3) loam, brown (10YR 4.5/3) when dry; peds have dark brown coats (10YR 3/3), dark brown to brown (10YR 4/3) when dry; moderate medium prismatic structure, separating to moderate medium angular blocky structure; hard when dry, friable when moist; many roots; moderate continuous clay films on horizontal ped faces, moderate patchy clay films on vertical ped faces; noncalcareous; slightly acid; clear smooth boundary.

B_{3ca1} 15-20.5" Light olive brown (2.5Y 5/4) loam, light yellowish brown (2.5Y 6/4) when dry; peds have olive brown coats (2.5Y 4/4), light olive brown when dry; weak to moderate medium prismatic structure, separating to moderate medium to coarse angular blocky structure; hard when dry, firm when moist; moderate amount of roots; common fine distinct lime concretions; moderate amount of carbonate segregated in threads; mildly

alkaline; clear wavy boundary.

B_{3ca2} 20.5-24" Mottled olive brown to light olive brown (2.5Y 4.5/4) loam, light olive brown to light yellowish brown (2.5Y 5.5/4) when dry; peds have olive brown coats (2.5Y 4/4), light olive brown (2.5Y 5/4) when dry; few fine distinct brownish yellow (10YR 6/8 D) iron mottles; weak medium to coarse prismatic structure, separating to moderate medium angular blocky structure; very hard when dry, firm when moist; moderate amount of roots; moderate amount of lime coated pebbles; common medium distinct lime concretions; moderate amount of carbonate segregated in threads; mildly alkaline; clear wavy boundary.

C_{ca} 24-36" Mottled olive brown to light olive brown (2.5Y 4.5/4) loam, light yellowish brown (2.5Y 6/4) when dry; common fine prominent dark red (2.5YR 3/6 D) iron mottles; moderate angular blocky structure; very hard when dry, friable when moist; few roots; moderate amount of lime coated pebbles; many coarse distinct lime concretions; large amount of carbonate segregated in threads, moderately alkaline; clear wavy boundary.

C_1 36-46" Mottled light olive brown (2.5Y 5/4) loam, light yellowish brown (2.5Y 6/4) when dry; common medium prominent dark red (2.5YR 3/6 D) iron mottles; weak horizontal blocky structure; very hard when dry, firm when moist; few roots; moderate amount of lime coated pebbles; common fine faint lime concretions; large amount of disseminated carbonate; moderately alkaline; gradual wavy boundary.

C_2 46-60" Mottled light olive brown (2.5Y 5/4) loam, light yellowish brown (2.5Y 6/4) when dry; common fine prominent dark red (2.5YR 3/6 D) iron mottles; weak horizontal blocky structure; very hard when dry, firm when moist; few roots; moderate amount of lime coated pebbles; common fine faint lime concretions; large amount of disseminated carbonate; moderately alkaline.

Site 10

Sample No.: S58-Minn-26-1 Date: 8-17-58
Soil Type: Barnes loam. Area: Grant Co. Minn.
Classification: Chernozem.
Location: 240' W., 260' S of NE cor. Sec. 10, Twp. 127 N, Rg. 42 W.
Vegetation: Cultivated for small grains.
Parent Material: Friable glacial till, Mankato substage.

Physiographic Position: Upland till plain, 100' W. of crest on long slope to slough which drains into a tributary of Pomme de Terre River.
Topography: Rolling, Relief 30' in area, sloping at site.
Slope: 3% to W.
Erosion: Slight.
Drainage: Well.
Permeability: Moderate.
Moisture: Moist to 14", dry to 40", moist.

Soil Profile: Barnes loam.

A_p 0-7" Black (10YR 2/1) clay loam, very dark gray to dark gray (10YR 3.5/1) when dry; crumbs have very dark gray brown coats (10YR 3/2) when dry; weak medium to fine crumb structure; hard when dry, friable when moist; numerous roots; noncalcareous; mildly alkaline; abrupt smooth boundary.

B_{21} 7-10" Black (10YR 2/1) clay loam, dark gray (10YR 4/1) when dry; peds have very dark gray brown to dark gray brown coats (10YR 3.5/2) when dry; weak medium prismatic structure separating to moderate medium angular blocky structure; hard when dry, friable when moist; many to numerous roots; thin patchy clay films on both horizontal and vertical ped faces; noncalcareous; neutral; clear wavy boundary.

B_{22} 10-16" Dark brown to brown (10YR 4/3) clay loam, brown (10YR 5/3) when dry; peds have very dark gray brown to dark brown coats (10YR 3/2.5), dark brown to brown (10YR 4/3) when dry; moderate medium prismatic structure separating to moderate medium to fine prismatic structure in turn separating to moderate to strong medium angular blocky structure; very hard when dry, friable to firm when moist; moderate amount of roots; moderate continuous clay films on vertical ped faces, thick continuous clay films on horizontal ped faces; noncalcareous; neutral; clear wavy boundary.

B_{3ca} 16-22" Light olive brown (2.5Y 5/4) clay loam, light yellowish brown (2.5Y 6/4) when dry; weak to moderate medium prismatic structure separating to moderate medium to fine prismatic structure in turn separating to moderate medium angular blocky structure; very hard when dry, firm to friable when moist; moderate amount of roots; few pebbles; moderately thick continuous clay films on vertical ped faces, thick continuous clay films on horizontal ped faces; few fine faint lime segregations as threads; slight amount of disseminated carbonates; moderately alkaline; clear smooth boundary.

C_{ca1} 22-28" Mottled light olive brown to light yellowish brown (2.5Y 5.5/4) clay loam, pale yellow (2.5Y 7/4) when dry; few fine distinct brownish yellow (10YR 6/8 D) iron mottles; weak coarse prismatic structure separating to moderate coarse angular blocky structure in turn separating to moderate fine angular blocky structure; very hard when dry, friable to firm when moist; few roots; few pebbles; common fine faint soft lime concretions; large amount of segregated carbonates; strongly alkaline; clear smooth boundary.

C_{ca2} 28-40" Mottled light olive brown (2.5Y 5/4) clay loam, light yellowish brown (2.5Y 6/4) when dry; few medium distinct dark red (2.5Y 3/6 D) iron mottles; weak very coarse prismatic structure separating to weak horizontal blocky structure; very hard when dry, friable when moist; few roots; moderate amount of pebbles; many medium faint hard lime concretions; lime cemented horizon; large amount of disseminated carbonates; strongly alkaline; clear wavy boundary.

C_1 40-50" Mottled olive brown to light olive brown (2.5Y 4.5/4) silt loam, light yellowish brown (2.5Y 6/4) when dry; common medium prominent dark red (2.5YR 3/6 D) iron mottles, few fine distinct black (10YR 2/1 D) manganese mottles, many medium faint light gray (2.5Y 7/2 D) mottles; weak horizontal blocky structure; very hard when dry, firm when moist; few roots; moderate amount of pebbles; common medium faint hard lime concretions; large amount of disseminated carbonates; strongly alkaline; gradual smooth boundary.

C_2 50-60" Mottled light olive brown (2.5Y 5/4) loam to silt loam, light yellowish brown (2.5Y 6/4) when dry; many medium prominent dark red (2.5YR 3/6 D) iron mottles, few fine distinct black (10YR 2/1 D) manganese mottles, many medium faint light gray (2.5Y 7/2 D) mottles; weak horizontal blocky structure; very hard when dry, firm when moist; few roots; moderate amount of pebbles; common medium faint hard lime concretions; large amount of disseminated carbonates; strongly alkaline.

Site 11

Sample No.: S58-Minn-56-1 Date: 8-16-58
Soil Type: Barnes loam. Area: Ottertail Co. Minn.
Classification: Chernozem.
Location: 3/10 mi. S., 2/10 mi. W. of NE cor. Sec. 20, Twp. 131 N, Rg. 43 W.

Vegetation: Alfalfa, Brome hay. Last cultivated in 1954.
Parent Material: Friable glacial till, Mankato substage.
Physiographic Position: Upland till plain, middle of 400' long slope, slough 200' to W.
Topography: Undulating, relief 20' area, nearly level at site.
Slope: 2% to W.
Erosion: Slight.
Drainage: Well.
Permeability: Moderate.
Moisture: Dry.
Note: Very few of the granite minerals were decomposed. Lime coating on pebbles from 17-60". Organic tonguing to 17".

Soil Profile: Barnes loam.

A_p 0-5" Black (10YR 2/1) loam, very dark gray (10YR 3/1) when dry; moderate medium crumb and angular blocky structure; slightly hard when dry, friable when moist; numerous roots; few pebbles; noncalcareous; neutral; abrupt smooth boundary.

B_{21} 5-10" Very dark gray brown (10YR 3/2) loam, dark gray brown (10YR 4/2) when dry; peds have black to very dark brown coats (10YR 2/1.5), very dark gray brown (10YR 3/2) when dry; weak coarse prismatic structure separating to moderate medium prismatic structure in turn separating to moderate medium angular blocky structure; slightly hard when dry, friable when moist; many roots; few pebbles; thin patchy clay films on vertical ped faces, moderate continuous clay films on horizontal ped faces; noncalcareous; mildly alkaline; clear wavy boundary.

B_{22} 10-17" Dark brown to brown (10YR 4/3) loam; brown (10YR 4.5/3) when dry; peds have dark brown coats (10YR 3/3); dark brown to brown (10YR 4/3) when dry; weak coarse prismatic structure separating to moderate fine to medium prismatic structure in turn separating to moderate medium angular blocky structure; hard when dry, friable to very friable when moist; many roots; few pebbles; thin to moderate patchy clay films on vertical ped faces, moderate continuous clay films on horizontal ped faces; noncalcareous; moderately alkaline; clear wavy boundary.

B_{3ca} 17-22" Mottled brown to dark brown (10YR 4/3) loam, brown (10YR 5/3) when dry; peds have dark brown coats (10YR 3.5/3), brown to pale brown (10YR 5.5/3) when dry; few fine distinct brownish yellow (10YR 6/8 D) iron mottles;

weak medium to coarse prismatic structure separating to moderate medium angular blocky structure; hard when dry, firm when moist; moderate amount of roots; moderate amount of pebbles; few fine distinct lime segregations as threads; slight amount of disseminated carbonates; strongly alkaline; clear wavy boundary.

C_{cal} 22-28" Mottled olive brown to light olive brown (2.5Y 4.5/4) loam, light yellowish brown (2.5Y 6/4) when dry; few fine to medium distinct brownish yellow (10YR 6/8 D) iron mottles; weak coarse prismatic structure separating to moderate medium angular blocky and weak horizontal blocky structure; very hard when dry, firm to friable when moist; moderate amount of roots; moderate amount of pebbles; few medium distinct soft lime concretions; large amount of disseminated carbonates; strongly alkaline; clear smooth boundary.

C_{ca2} 28-39" Mottled light olive brown (2.5Y 5/4) loam, pale yellow (2.5Y 7/4) when dry; few fine distinct dark red (2.5YR 3/6 D) iron mottles; weak very coarse prismatic structure separating to moderate coarse angular blocky and weak horizontal blocky structure; very hard when dry, firm when moist; few roots; moderate amount of pebbles; many medium distinct very hard lime concretions; lime cemented horizon; large amount of disseminated carbonates; strongly alkaline; clear smooth boundary.

C_1 39-48" Mottled light olive brown (2.5Y 5/4) loam, light yellowish brown (2.5Y 6/4) when dry; many medium prominent dark red (2.5YR 3/6 D) iron mottles, common medium faint gray brown (2.5Y 5/2 D) mottles; weak horizontal blocky structure; very hard when dry, firm when moist; few roots; moderate amount of pebbles; common medium distinct hard lime concretions; few fine distinct threads of segregated lime; large amount of disseminated carbonates; strongly alkaline; gradual smooth boundary.

C_2 48-60" Mottled light olive brown (2.5Y 5/4) silt loam, pale yellow (2.5Y 7/4) when dry; many large prominent dark red (2.5YR 3/6 D) iron mottles, few fine distinct black (10YR 2/1 D) manganese mottles, common medium distinct light gray (2.5Y 7/2 D) mottles; weak horizontal blocky structure; very hard when dry, firm when moist; few roots; moderate amount of pebbles; common medium distinct hard lime concretions, few fine distinct threads of segregated lime; moderate amount of disseminated carbonates; strongly alkaline.

C_u 54-57" Multicolored sands with bright red-orange iron coats; single grain structure; moderate amount of carbonate; abrupt smooth boundary. (not sampled)

Discussion of Field Results

Local Climate at Sites

Local climate varies more among the sites than is shown in Figures 5 and 6. The average annual precipitation and average annual temperature at weather reporting stations located as close as possible to the sites is shown in Table I.

TABLE I. AVERAGE ANNUAL PRECIPITATION AND TEMPERATURE*

Sites	1 and 2	3	4 and 5	6 and 7	8 and 9	10 and 11
Precipitation (in.)	17.8	18.5	19.6	19.1	20.9	23.3
Temperature (°F.)	42.0	44.3	43.5	42.4	44.1	42.6

* United States Weather Bureau Data (41).

Table I indicates a decided difference in the local climate among sites. There is a gradual increase in temperature as one moves south from sites 1 and 2 through 6, 7, 4 and 5 to site 3. The same is true from sites 1 and 2 to sites 8 and 9, however, from sites 1 and 2 to sites 10 and 11 the temperature increase is nil. In general, precipitation follows the same pattern, that is, there is an increase as one goes southward from sites 1 and 2. The micro-climate at the sites is considered to be approximately the same as macro-climate at area weather reporting stations.

Profile Colors

In the Chernozem soil zone a low value and low chroma color generally indicates the existence of high organic matter content in the soil. A high chroma and moderate value color generally

indicates good pedologic drainage. Thus in two different ways one may infer from color soil characteristics that are not so readily determined.

The average dry color of each of the soil horizons at the sites is shown in Table II.

TABLE II. AVERAGE COLORS* OF SOIL HORIZONS

Sites	1 and 2	3	4 and 5	6 and 7	8 and 9	10 and 11
Horizons						
A1 or A1p	10YR 4/1 dark gray	10YR 3.5/2 dark gray brown	10YR 3.8/1 dark gray	10YR 3.5/1 dark gray	10YR 2.8/1.5 very dark gray brown	10YR 3.3/1 very dark gray
A12			10YR 3.3/2 very dark gray brown	10YR 3.5/1.5 dark gray brown	10YR 3/1.5 very dark gray brown	
AB		10YR 4/2 dark gray brown			10YR 3.3/1.5 very dark gray brown	
B2 or B21	10YR 4.3/1.5 dark gray brown	10YR 5/2 gray brown	10YR 4.8/3 brown	10YR 4.5/3 brown	10YR 4.8/3 brown	10YR 4/1.5 dark gray brown
B22		10YR 4.5/2 gray brown	10YR 4.8/25 brown	10YR 5/3 brown		10YR 4.8/3 brown
B3ca or B3ca1	2.5Y 6.5/3 pale yellow	2.5Y 5.5/4 light yellow brown	2.5Y 5/4 light olive brown	2.5Y 5.3/4 light olive brown	2.5Y 6/4 light yellow brown	2.5Y 5.5/3.5 light yellow brown
B3ca2		2.5Y7/4 pale yellow				

TABLE II. (Continued)

Sites	1 and 2	3	4 and 5	6 and 7	8 and 9	10 and 11
Horizons						
Cca or Ccal	2.5Y 6/3.5 light yellow brown	2.5Y 6/4 light yellow brown	2.5Y 6/4 light yellow brown	2.5Y 6/4 light yellow brown	2.5Y 7/4 pale yellow	2.5Y 6.5/4 pale yellow
Cca2			2.5Y 6.5/4 pale yellow	2.5Y 5.5/4 light yellow brown		2.5Y 6.5/4 pale yellow
C1	2.5Y 6/3.5 light yellow brown	2.5Y 7/4 pale yellow	2.5Y 6/4 light yellow brown	2.5Y 6/4 light yellow brown	2.5Y 6.5/4 pale yellow	2.5Y 6/4 light yellow brown
C2	2.5Y 6.5/3 pale yellow	2.5Y 7/4 pale yellow	2.5Y 6/4 light yellow brown		2.5Y 6.5/4 pale yellow	2.5Y 6.5/4 pale yellow
C3	2.5Y 6/4 light yellow brown					
Ccs				2.5Y6/4 light yellow brown		

* Munsell notation for dry, crushed samples.

The hue designation is constant for the same horizon at all sites. There is little or no difference in value or chroma among the sites in the A horizon, except slightly higher chroma at sites 3, 8 and 9.

In the B_2 horizon, B_{21} + B_{22}, rather marked differences in color are observable. All the sites have a higher chroma than sites 1 and 2 by 0.5 to 1.5 units. The same situation exists in the B_{3ca} horizon except the increase in chroma is 0.5 to 1.0 unit. The value in the B_2 horizon at all sites is also higher than at sites 1 and 2, but in the B_{3ca} horizon there is a decrease in value from sites 1 and 2.

In the C_{ca} and C horizons no great differences are observable in value and chroma. Also there seems to be little difference among the sites when sites 1 and 2 are excluded.

This combination of higher chroma and value gives all the other sites a lighter, more brown B_2 horizon than is found at sites 1 and 2. This change could be expected due to the colder drier conditions that prevail at sites 1 and 2.

Profile Development

The depth to which the profiles are developed and the depth to free carbonate is given in Table III.

Sites 10 and 11, which have the highest precipitation, have the deepest leaching of carbonates but not the deepest development. The greatest development is found at site 3 where the highest temperature is reported but the precipitation the second lowest of all the sites.

Sites 1, 2, 4, 5, 6 and 7 are similar in both depth of development and depth to free carbonate.

The carbonate and development seem to follow the climatic factors quite closely. Comparing sites 1 and 2 with 8 and 9 show a deeper development and leaching of carbonates at sites 8 and 9. These sites

TABLE III. AVERAGE SOIL HORIZON DEPTH

Site	1 and 2	3	4 and 5	6 and 7	8 and 9	10 and 11
Horizon						
A1 or A1p	0-6	0-3	0-2	0-2	0-2	0-6
A12			2-4	2-4.5	2-5	
AB		3-6.5			5-7.5	
B2 or B21	6-14	6.5-11.5	4-8.5	4.5-8.5	7.5-15.5	6-10
B22		11.5-14	8.5-12.5	8.5-14		10-16.5
B3ca or B3ca1	14-19	14-19	12.5-16.5	14-17.5	15.5-24	16.5-22
B3ca2		19-26				
Cca or Cca1	19-33.5	26-35	16.5-23.5	17.5-25		22-28
Cca2			23.5-30.5	25-31	24-36	28-39.5
C1	33.5-44	35-41	30.5-47	31-45 (46-60)*	36-47	39.5-49
C2	44-60	41-60	47-60		47-60	49-60
Cca				45-60 (31-46)*		

* Site 6

also have a considerably higher temperature and precipitation than sites 1 and 2.

Comparison of sites 1 and 2 with 10 and 11 shows that the same general characteristics are evident. However, the carbonate is leached to a greater depth and the development does not go as deep as it did

at sites 8 and 9. This could be expected as the precipitation is higher while the temperature is considerably lower at sites 10 and 11.

Soil Structure

Examination of the profile descriptions shows that the A horizons have a crumb type structure. The B horizons have a prismatic primary structure separating to blocky type secondary structure. The C horizons have a horizontal blocky type structure.

The main difference noted among the sites is the difference in structure grade of the B_2 horizon. There is a slightly stronger grade of structure as one goes south from sites 1 and 2 through sites 4, 5, 6 and 7 to site 3. There is also a decrease in the class of the secondary blocks through this same region.

Comparison of sites 1 and 2 with sites 8 and 9 shows little difference in grade or class of structure. However, when sites 1 and 2 are compared with sites 10 and 11 a slightly weaker grade and smaller class of structure is seen at sites 10 and 11.

This seems generally to follow climatic areas. When the temperature increases and precipitation decreases there is an increase in strength of grade and decrease in the class of structure. When temperature and precipitation both increase there is little change, but when temperature remains constant and precipitation increases there is a decrease in both strength of grade and class of structure.

Clay Films

Clay films are the accumulation of clay around the outside of

the ped. The exact mode of accumulation is unknown but evidence points to the movement of clay from the A horizon into the B horizon. Another possibility is the formation of the clay film in situ from the weathering of the minerals present in the B horizon.

In comparing sites 1 and 2 with sites 3, 4, 5, 6 and 7 an increase in thickness and coverage of the ped face is evident as one moves southward. That is, the clay films at sites 1 and 2 are moderate in thickness and patchy to continuous in coverage. Sites 4, 5, 6 and 7 are also moderate in thickness but continuous to patchy in coverage. Site 3, the most southerly site, is moderately thick and continuous to patchy in coverage.

Sites 8 and 9 are generally moderately thick and continuous to patchy in coverage. Thus the clay films at sites 8 and 9 are thicker and more continuous than at sites 1 and 2.

At site 10 the clay films are moderately thick and continuous in coverage while at site 11 they are moderately thin to moderate in thickness and patchy to continuous in coverage.

Site 10, however, as can be seen in the particle size distribution in the pages that follow, is considerably higher in total clay content than site 11 or any of the other sites. This could cause the thicker more continuous clay films and leads one to question the validity of the assumption that the parent material is the same at all sites.

In comparing site 11 with sites 1 and 2 the thickness of the clay films are about the same but the coverage of the ped is slightly greater at site 11.

Summary of Field Results

Sites 4, 5, 6 and 7, the border sites, have a higher chroma and value, stronger grade and smaller class of structure and more continuous clay films in the B_2 horizon than sites 1 and 2, but are about the same in these characteristics as site 3.

Sites 8 and 9 have a greater depth to free carbonate; deeper development; higher chroma and value; and thicker, more continuous clay films in the B_2 horizon than sites 1 and 2.

Sites 10 and 11 are also deeper to free carbonate and have deeper development than sites 1 and 2. Further they have a higher value and chroma, weaker grade and smaller class of structure in the B_2 horizon than sites 1 and 2.

These characteristics, observable in the field, indicate that the border sites and the eastern sites (8, 9, 10 and 11) should be separated from sites 1 and 2.

The differences in climate and vegetation that exist or did exist over this three-state area would also lead one to expect these differences.

LABORATORY RESULTS AND DISCUSSION

Laboratory Results

The results of the laboratory analyses are given in Tables IV, VI and VII.

The horizon and depth designations given are the same as those used in the profile descriptions. Where these designations differ from the previous description the data from the previous sample are assigned to the closest possible corresponding depth.

This difference is due mainly to two factors. One factor is the increase in knowledge of soil morphology from the time the sampling was done to the present. The second factor is the inability to return to the exact site from which the previous sampling had been made.

In Tables IV, VI and VII, if the column is blank, it signifies that the determination was not made. If the column is marked with a dash (-), the determination was made but the amount determined was below the limits of accuracy.

Discussion of Laboratory Results

Particle Size Distribution

Table IV shows the particle size distribution for the eleven sites. The major difference between the sites is in clay content, especially in the clay increase in the B horizon over the A or C horizon. These clay increases may be genetically related to soil formation or they may be inherited characteristics from the parent material of the soil.

TABLE IV. PARTICLE SIZE DISTRIBUTION, pH AND MOISTURE AT SATURATION

Horizon	Depth inches	Particle Size Distribution* (in mm.) >2	Sand 2-.05	Silt .05-.002	Clay <.002	Textural class	pH Sat. paste	Moist. at sat. %
Site 1								
A1p	0-6	2.1	34.2	34.3	21.5	l	7.7	46.5
A12	6-8	1.0	37.2	39.3	23.5	l	7.8	49.4
B2	8-16	2.5	39.1	37.8	23.1	l	7.8	44.4
B3ca	16-24	3.6	34.0	39.9	26.1	l	7.9	45.1
Cca	24-31	2.8	31.7	45.1	23.2	l	7.8	45.7
C1[1]	(31-39	2.6	29.0	45.1	25.9	l	7.9	47.8
	(39-47	4.3	38.2	39.0	22.8	l	7.9	42.5
C2	47-60	4.8	47.7	33.1	19.2	l	8.0	35.3
Site 2								
A1p	0-6	1.4	34.3	38.2	27.5	cl	7.7	56.5
B2	6-12	2.9	42.8	30.5	26.7	l	7.7	45.9
B3ca[2]	12-14)	3.5	36.0	36.5	27.5	cl	8.0	42.1
Ccal[2]	14-21)							
Cca2	21-36	3.7	36.1	35.5	28.4	cl	8.6	43.6
C1	36-41	2.0	25.9	43.2	30.9	cl	8.3	47.3
C2	41-50	3.7	39.3	36.8	23.9	l	8.4	40.2
C3	50-60	3.8	36.3	37.5	26.2	l	8.4	44.1
Site 3[3]								
A1	0-3)	1.0	34.5	43.2	22.3	l	5.9	
AB	3-6.5)							
B21	6.5-11.5)	1.0	37.8	32.1	30.1	cl	6.8	
B22	11.5-14)							
B3cal	14-19	0.5	34.8	35.1	30.1	cl	7.1	
B3ca2	19-26)	2.0	45.4	32.1	22.5	cl [1]	7.7	
Cca	26-35)							
C1	35-41)							
C2	41-60	2.0	43.6	35.0	21.4	l	7.9	
C2	53-65	4.0	46.9	32.3	20.8	l	7.9	
Site 4								
A11	0-2	1.0	31.7	46.9	21.4	l	6.3	68.8
A12	2-4	1.5	36.1	41.9	22.0	l	6.1	53.9
B21	4-9	1.3	39.2	33.8	27.0	cl-l	6.4	45.9
B22	9-13	2.0	43.3	30.7	26.0	l	6.7	39.1
B3ca	13-17	3.2	48.0	29.7	22.3	l	7.9	40.0
Ccal	17-23	4.6	42.9	33.4	23.7	l	8.3	39.3
Cca2	23-30	3.8	35.5	36.5	28.0	cl	8.9	60.4
C1	30-48	3.2	38.5	36.7	24.8	l	8.8	57.8
C2	48-60	2.7	40.1	36.7	23.2	l	8.4	44.2

TABLE IV. (Continued)

Horizon	Depth inches	Particle Size Distribution[a] (in mm.) (percent) >2	Sand 2-.05	Silt .05-.002	Clay <.002	Textural class	pH Sat. paste	Moist. at Sat. %
Site 5								
A11	0-2	0.7	33.9	45.3	20.8	l	6.6	65.9
A12	2-4	0.9	40.9	36.9	22.2	l	6.4	51.7
B21	4-8	1.4	39.5	30.9	29.6	cl	6.4	42.0
B22	8-12	1.7	40.4	30.9	28.7	cl	6.7	41.2
B3ca	12-16	2.8	37.6	33.2	29.2	cl	7.8	43.4
Cca1	16-24	3.8	34.5	34.8	30.7	cl	8.4	39.1
Cca2	24-31	4.7	33.9	35.7	30.4	cl	8.6	60.7
C1	31-46	3.5	36.0	36.7	27.3	cl-l	8.5	49.5
C2	46-60	3.0	38.9	35.9	25.2	l	8.2	47.4
Site 6								
A11	0-2	0.7	37.4	42.7	19.9	l	6.3	61.3
A12	2-5	1.3	45.6	30.0	24.4	l	6.2	48.2
B21	5-9	1.6	43.2	31.3	25.5	l	6.8	45.7
B22	9-14	1.9	44.0	31.9	24.1	l	7.6	36.4
B3ca	14-17	2.2	39.4	35.4	25.2	l	8.3	40.2
Cca1	17-24	4.3	40.8	35.9	23.3	l	8.5	41.8
Cca2	24-30	3.1	40.4	37.3	22.3	l	8.1	41.3
Ccs	30-46	3.3	42.6	36.4	21.0	l	8.3	42.0
C1	46-60	2.8	40.5	41.3	18.2	l	8.2	38.5
Site 7								
A11	0-2	0.2	41.5	37.3	21.2	l	7.8	63.6
A12	2-4	0.5	50.4	29.6	20.0	l	7.8	49.2
B21	4-8	1.1	49.9	28.6	21.5	l	7.7	41.2
B22	8-14	1.4	47.0	29.8	23.2	l	7.5	35.8
B3ca	14-18	2.3	47.1	31.5	21.4	l	8.1	34.8
Cca1	18-26	2.4	40.2	33.6	26.2	l	8.2	37.6
Cca2	26-32	2.1	40.1	35.0	24.9	l	8.2	41.8
C1	32-45	3.2	44.2	33.9	21.9	l	8.4	42.0
Ccs	45-60	2.7	45.4	35.0	19.6	l	8.4	39.5
Site 8								
A11	0-2	-	21.2	50.7	28.1	cl	6.6	83.9
A12	2-5	5.6	36.4	38.4	25.2	l	6.9	68.1
AB	5-7.5	1.9	43.9	29.2	26.9	l	6.6	59.1
B2	7.5-16	1.9	41.6	32.6	25.8	l	6.8	49.8
Cca1	16-24	2.6	39.7	38.4	21.9	l	7.7	47.0
Cca2	24-36	7.9	41.1	38.4	20.5	l	7.8	45.3
C1	36-48	4.2	42.3	40.8	16.9	l	8.3	42.7
C2	48-60	4.5	40.2	39.6	20.2	l	8.3	42.4

TABLE IV. (Continued)

Horizon	Depth inches	Particle Size Distributions* (in mm.) >2	Sand 2-.05	Silt .05-.002	Clay <.002	Textural class	pH Sat. paste	Moist. at Sat. %
Site 9								
A11	0-2	-	24.0	49.9	26.1	l	6.4	85.3
A12	2-5	6.8	46.4	31.7	21.9	l	6.2	67.4
AB	5-7.5	16.2	63.7	18.1	18.2	sl	6.4	58.7
B2	7.5-15	3.3	41.1	32.7	26.2	l	6.4	50.9
B3cal[4]	15-20.5)							
B3ca2[4]	20.5-24)	7.2	33.2	43.6	23.2	l	7.8	36.7
Cca	24-36	9.3	34.6	42.9	22.5	l	8.0	36.1
C1	36-46	6.7	35.2	41.8	23.0	l	8.0	39.2
C2	46-60	8.8	35.2	42.1	22.7	l	8.1	38.4
Site 10								
Ap	0-7	1.3	21.8	47.6	30.6	cl	6.9	64.1
B21	7-10	1.8	20.6	48.1	31.3	cl	6.9	58.9
B22	10-16	1.7	24.3	42.6	33.1	cl	6.9	49.5
B3ca	16-22	9.7	28.9	41.4	29.7	cl	7.5	46.6
Ccal	22-28	7.3	26.8	42.9	30.3	cl	7.8	44.8
Cca2	28-40	5.4	26.2	43.6	30.2	cl	7.9	46.7
C1	40-50	6.3	12.9	60.9	26.2	sil	7.9	52.0
C2	50-60	7.2	24.7	49.8	25.5	l-sil	7.9	47.2
Site 11								
Ap	0-5	1.8	34.0	40.6	25.4	l	6.6	57.9
B21	5-10	2.1	36.3	39.1	24.6	l	7.0	55.9
B22	10-17	2.4	50.0	29.2	20.8	l	7.4	49.1
B3ca	17-22	10.2	31.1	42.9	26.0	l	7.4	43.4
Ccal	22-28	8.3	28.5	44.9	26.6	l	8.0	41.8
Cca2	28-39	6.5	27.9	46.3	25.8	l	7.9	43.9
C1	39-48	7.2	24.7	48.7	26.6	l	7.9	45.9
C2	48-60	5.3	23.5	53.7	22.8	sil	7.8	45.2

1 Horizons were named by Johnson (18) as follows: Cca2, 31-39" and C1, 39-47".

2 Horizon was named Ccal, 12-21" by Johnson (19).

3 Horizons were named by Hogen (27) as follows: A1, 0-7"; B2, 7-14"; B3, 14-18"; Cca, 18-42"; C1, 42-53"; and C2, 53-65".

4 Horizon was named Ccal, 16-24" by Hogen (29).

* All particle size distribution analyses by the Soil Survey Laboratories.

These clay increases are summarized in Table V.

TABLE V. RELATIVE CLAY INCREASE

Site	1	2	3	4	5	6	7	8	9	10	11
Horizon	Percent										
B over A	12	0	35	15	36	12	7	0	0	3	0
B over C	9	0	38	0	3	17	5	32	0	12	0

As can be seen in Table V, no increase in clay was found at sites 2, 9 and 11. Site 8 has an increase in the B over the C horizon but no increase in the B over the A horizon. This leads one to suspect that the increase is not genetic but that the clay was formed in situ.

The increase at sites 1, 7 and 10 is rather small but does exist.

The greatest increase is found at site 3 followed by sites 5, 6, and 4. Using the average clay increase for the sites there is a definite trend for increase of clay in the B horizon as one moves from north to south, that is, from sites 1 and 2 through sites 6 and 7, 4 and 5 to site 3. This increase in clay of the B horizon takes place through an area of gradually increasing temperature and precipitation. The precipitation at the two extremes; sites 1 and 2, and site 3; is not greatly different but the increase in temperature is relatively great.

No increase of clay in the B horizon is evident at sites 8, 9, 10 and 11 over sites 1 and 2.

As mentioned under 'Clay Films' the total clay content of site 10 is higher than at any of the other sites. This can be seen from Table

IV. This clay content, while not large, in absolute percentage is of sufficient magnitude to question whether it is not a different parent material than the other sites.

If the parent material is different, the series definition (38) would require the separation of these soils from sites 1 and 2.

pH

The pH of the soil horizons is shown in Table IV. This indicates that sites 1, 2 and 7 are mildly alkaline at the surface to moderately alkaline in the subhorizons. Site 3 is medium acid in the surface to moderately alkaline in the lower horizon. Sites 4, 5, 6, 8 and 9 are slightly acid at the surface and become moderately alkaline in the lower horizons. Sites 10 and 11 are neutral at the surface to moderately alkaline in the subhorizons.

When the precipitation and temperature found in Table I are compared with the pH of the surface horizons it is found that the sites with the highest acidity also have the highest temperature but lie between the precipitation extremes. The sites with the lowest acidity are found where the precipitation is highest and the temperature is close to the lowest value.

Sites 1 and 2, with acidity between the two groups above, have the lowest temperature and precipitation.

Extractable Calcium and Magnesium

Extractable calcium and magnesium are shown in Table VI. At all sites there is a decrease in calcium from the surface through the B_2

horizon. The greatest amount of calcium is found at sites 1 and 2 and the least at sites 4 and 5. These were also the sites with the highest and lowest pH, respectively. The calcium decrease gives an indication of the leaching of calcium from the A and B horizons. For magnesium, the converse is generally true. There is a gradual increase in magnesium with depth. Sites 8 and 11 however, do not exhibit this increase but rather show a decrease. The magnitude of magnesium increase is greatest at sites 1 and 2.

Extractable Hydrogen

As can be seen in Table VI, there is a decrease in hydrogen with depth at all sites. Sites 1, 2 and 7 have the least hydrogen in the A horizon and sites 4, 5, 6 and 8 the most. Sites 10 and 11 lie between these two groups.

This grouping for hydrogen parallels both the pH and extractable calcium parameters.

Extractable and Soluble Potassium

Extractable and soluble potassium are both shown in Table VI. There is a gradual decrease in potassium with depth at all sites and little difference in magnitude among the sites.

Extractable and Soluble Sodium

Extractable and soluble sodium are shown in Table VI. Soluble sodium is reported in me./100 gm. for site 3. To compare this with the other sites it becomes necessary to convert to the same basis, me./l. In this conversion 45% moisture at saturation will be assumed. The

TABLE VI. EXTRACTABLE CATIONS, SOLUBLE CATIONS AND EXCHANGEABLE SODIUM

Horizon	Depth inches	Extractable Cations me./100gm. Ca	Mg	H	Na	K	Exch. Na %	Sat. Extract Sol. me./l. Na	K
Site 1*									
A1p	0-6	21.6	4.8	1.2	0.3	0.9	0.2	0.2	0.4
A12	6-8	18.7	5.9	1.2	0.5	0.5	0.4	0.4	0.1
B2	8-16	13.5	7.2	-	0.5	0.2	0.5	0.4	-
B3ca	16-24							1.5	-
Cca	24-31							6.5	-
C1[1]	(31-39							13.9	-
	(39-47							21.5	0.1
C2	47-60							33.0	0.1
Site 2*									
A1p	0-6	24.4	7.2	2.2	-	0.6	-	-	0.1
B2	6-12	20.7	11.0	1.3	0.2	0.3	-	0.2	0.1
B3ca[2]	12-14)	27.6	12.8	-	0.7	0.2	0.2	0.6	0.1
Cca1[2]	14-21)								
Cca2	21-36							8.3	-
C1	36-41							19.1	-
C2	41-50							23.0	-
C3	50-60							23.9	-
Site 3[3]*									
A1	0-3)				0.1	1.2	-	.4	.4
AB	3-6.5)								
B21	6.5-11.5)				0.1	0.7	-	-	-
B22	11.5-14)								
B3ca1	14-19				0.1	0.7	-	-	-
B3ca2	19-26)								
Cca	26-35)				0.9	0.2	4	0.3	-
C1	35-41)								
C2	41-60				3.2	0.2	13	1.4	-
C2	53-65				3.4	0.2	15	1.5	-
Site 4									
A11	0-2	14.9	4.0	7.2	-	1.9	-	0.1	0.7
A12	2-4	12.7	4.1	6.0	-	1.3	-	0.1	0.9
B21	4-9	12.3	4.5	3.9	-	0.9	-	0.1	0.3
B22	9-13	11.3	5.7	2.4	-	0.4	-	0.1	0.2
B3ca	13-17				-	0.1	-	0.3	0.3
Cca1	17-23				0.2	-	0.6	2.8	-
Cca2	23-30				3.6	-	18.1	8.0	-
C1	30-48				7.3	-	26.3	48.0	0.1
C2	48-60				10.3	-	9.6	195.0	0.6

TABLE VI. (Continued)

Horizon	Depth inches	Extractable Cations me./100gm. Ca	Mg	H	Na	K	Exch. Na %	Sat. Extract Sol. me./l. Na	K
Site 5									
A11	0-2	13.9	3.8	6.1	-	1.5	-	0.2	0.6
A12	2-4	11.7	4.6	5.8	-	1.3	-	0.2	0.4
B21	4-8	12.2	6.4	3.9	-	0.9	-	0.3	0.3
B22	8-12	11.3	6.5	2.4	-	0.5	-	0.8	0.3
B3ca	12-16				-	0.3	-	2.0	0.2
Cca1	16-24				1.2	-	5.4	3.8	-
Cca2	24-31				4.8	-	19.3	25.3	-
C1	31-46				9.2	-	16.7	127.5	0.3
C2	46-60				10.8	-	10.6	185.0	0.5
Site 6									
A11	0-2	15.8	1.9	6.5	-	1.3	-	0.2	0.6
A12	2-5	13.0	3.8	4.3	-	1.1	-	0.2	0.6
B21	5-9	11.8	5.6	2.4	-	1.1	-	0.3	0.3
B22	9-14	15.1	5.9	1.2	-	0.9	-	0.4	0.7
B3ca	14-17				-	0.6	-	0.6	0.5
Cca1	17-24				0.6	0.5	3.2	2.0	0.5
Cca2	24-30				1.6	0.3	2.2	32.5	1.6
Ccs	30-46				3.9	0.1	8.2	67.5	0.8
C1	46-60				2.2	-	3.1	47.5	0.6
Site 7									
A11	0-2	21.3	1.8	1.1	-	1.1	-	0.4	0.5
A12	2-4	15.1	4.0	2.2	-	0.9	-	1.0	0.4
B21	4-8	9.9	6.6	2.2	0.2	0.7	0.5	2.3	0.3
B22	8-14	9.8	4.7	1.8	1.4	0.5	6.3	3.1	0.1
B3ca	14-18				1.4	0.5	6.6	4.4	0.1
Cca1	18-26				1.4	0.4	3.5	25.0	1.0
Cca2	26-32				4.1	0.3	10.5	65.0	1.6
C1	32-45				7.7	0.3	6.8	160.0	1.9
Ccs	45-60				8.7	0.3	3.9	207.5	1.9
Site 8									
A11	0-2	18.9	7.4	6.5	-	1.7	-	0.2	0.4
A12	2-5	18.2	4.7	4.2	-	1.0	-	0.2	0.3
AB	5-7.5	15.8	4.2	3.4	-	0.6	-	0.2	0.1
B2	7.5-16	14.6	4.2	2.2	-	0.5	-	0.4	-
Cca1	16-24				-	0.3	-	0.5	-
Cca2	24-36				-	0.3	-	0.8	-
C1	36-48				0.4	0.3	1.6	1.4	-
C2	48-60				0.4	0.3	1.7	2.0	-

TABLE VI. (Continued)

Horizon	Depth inches	Extractable Cations me./100gm. Ca	Mg	H	Na	K	Exch. Na %	Sat. Extract Sol. me./l. Na	K
Site 9									
A11	0-2	19.4	3.9	6.9	-	1.5	-	0.2	0.5
A12	2-5	13.9	4.5	6.2	-	0.6	-	0.2	-
AB	5-7.5	13.4	3.8	5.4	-	0.3	-	0.2	-
B2	7.5-15	11.9	3.9	3.4	-	0.2	-	0.3	-
B3ca1[5]	15-20.5								
B3ca2[5]	20.5-24				-	0.2	-	0.3	-
Cca	24-36				-	0.4	-	0.4	-
C1	36-46				-	0.2	-	0.4	-
C2	46-60				0.2	0.2	-	0.6	-
Site 10									
Ap	0-7	22.0	5.8	3.4	-	1.3	-	0.4	0.4
B21	7-10	18.2	5.7	3.6	-	0.5	-	0.4	0.1
B22	10-16	14.8	7.6	2.7	-	0.4	-	0.3	-
B3ca	16-22				0.4	0.4	2.4	0.3	0.1
Cca1	22-28				0.4	0.4		0.5	0.1
Cca2	28-40				0.4	0.3		0.6	0.1
C1	40-50				0.4	0.3		0.6	-
C2	50-60				0.4	0.1		0.5	-
Site 11									
Ap	0-5	17.2	5.3	3.9	-	2.4	-	0.1	1.0
B21	5-10	14.5	3.7	2.7	-	3.3	-	0.2	1.5
B22	10-17	8.4	3.1	1.4	-	3.7	-	0.1	2.4
B3ca	17-22				-	4.2	-	0.2	2.0
Cca1	22-28				-	2.6		0.2	1.1
Cca2	28-39				0.4	0.5		2.1	0.5
C1	39-48				0.4	0.2		1.1	0.1
C2	48-60				0.4	0.2		1.8	0.3

1 Horizons were named by Johnson (18) as follows: Cca2, 31-39" and C1, 39-47".

2 Horizon was named Cca1, 12-21" by Johnson (19).

3 Horizons were named by Mogen (27) as follows: A1, 0-7"; B2, 7-14"; B3, 14-18"; Cca, 18-42"; C1, 42-53"; and C2, 53-65".

4 Reported in me./100gm.

5 Horizon was named Cca1, 16-24" by Mogen (29).

* All analyses on sites 1, 2 and 3 by the Soil Survey Laboratories.

resulting soluble sodium values, in me./l., are as follows: 19-41", 6.7; 41-60", 31.1; 53-65", 33.3.

At all the sites the sodium content of the A and B horizons is low to nil. However, the lower horizons show a marked difference in sodium among the sites.

Sites 8, 9, 10 and 11 are practically free of sodium, while sites 1 and 2 have a moderate amount. Sites 3, 4, 5, 6 and 7 have more sodium than any of the other sites. Thus, the sites can be divided into groups having low, moderate and high sodium content in the lower horizons.

This grouping agrees with the average annual precipitation and temperature patterns from Table I.

The lowest sodium content is found where the precipitation is highest and the temperature is moderate. The moderate sodium content is found where the precipitation and temperature are lowest. The highest sodium content is found where the precipitation is moderate but the temperature is the highest.

Cation Exchange Capacity

The cation exchange capacity of the sites is shown in Table VII.

Cation exchange capacity is related to the amount of colloidal material present in the soil. This may be of either organic or inorganic composition.

All the sites show a decrease in exchange capacity with depth, and have about the same magnitude. Site 3 however, is lower in exchange capacity than the other sites, but as can be seen in Table VII, it has the lowest organic carbon content.

TABLE VII. CATION EXCHANGE CAPACITY, ELECTRICAL CONDUCTIVITY, $CaCO_3$ EQUIVALENT, ORGANIC CARBON, TOTAL NITROGEN AND C/N

Horizon	Depth inches	Cation Exch. Cap. me./100gm.	Elect. cond. Ec.x10^3	Organic* carbon %	Nitrogen %	C/N	$CaCO_3$ equiv. %
Site 1*							
A1P	0-6	28.8**	0.7	2.87	0.212	13.5	-
A12	6-8	26.8**	0.7	2.46	0.188	13.1	-
B2	8-16	21.4**	0.7	0.93	0.099	9.4	-
B3ca	16-24		1.2	0.56	0.060	9.3	25
Cca	24-31		3.5	0.39	0.040	9.8	19
C1[1]	(31-39		4.7	0.20	0.026	7.7	15
	(39-47		5.5	0.16	0.020	8.0	16
C2	47-60		6.5	0.14	0.015	9.3	16
Site 2*							
A1p	0-6	34.4**	0.5	3.49	0.307	11.4	-
B2	6-12	33.5**	0.6	1.36	0.138	9.8	5
B3ca[2]	12-14)						
Cca1[2]	14-21)		0.6	0.55	0.066	8.3	23
Cca2	21-36		1.9	0.23	0.030	7.7	26
C1	36-41		4.0	0.16	0.023	7.0	20
C2	41-50		5.0	0.14	0.017	8.2	17
C3	50-60		4.5	0.11	0.017	6.5	18
Site 3[3]*							
A1	0-3)	22.8	0.7	2.62			-
AB	3-6.5)						
B21	6.5-11.5)	23.6	0.8	0.88			-
B22	11.5-14)						
B3ca1	14-19	23.0	1.0	0.82			-
B3ca2	19-26)						
Cca	26-35)	13.8	1.4	0.39			17
C1	35-41)						
C2	41-60	13.6	4.0	0.18			12
C2	53-65	12.8	5.0	0.20			13
Site 4							
A11	0-2	31.3	1.9	5.62	0.464	12.1	
A12	2-4	27.4	0.9	3.48	0.316	11.0	
B21	4-9	26.2	0.5	1.82	0.169	10.8	
B22	9-13	22.1	0.4	1.16	0.114	10.2	-
B3ca	13-17	18.1	0.4	0.86	0.079	10.9	8.4
Cca1	17-23	16.3	0.5	0.53	0.042	12.6	15.6
Cca2	23-30	17.1	0.9	0.30	0.033	9.1	19.9
C1	30-48	17.1	3.8	0.17	0.021	8.1	12.9
C2	48-60	17.7	15.0	0.14	0.018	7.8	9.4

TABLE VII. (Continued)

Horizon	Depth inches	Cation Exch. Cap. me./100gm.	Elect. cond. Ec.x10^3	Organic* carbon %	Nitrogen %	C/N	$CaCO_3$ equiv. %
Site 5							
A11	0-2	28.2	1.5	5.47	0.391	14.0	
A12	2-4	25.4	0.5	3.17	0.274	11.6	
B21	4-8	26.4	0.4	1.49	0.140	10.6	
B22	8-12	25.1	0.3	1.10	0.111	9.9	-
B3ca	12-16	21.6	0.5	0.82	0.091	9.0	14.2
Cca1	16-24	18.4	0.5	0.50	0.060	8.3	21.0
Cca2	24-31	17.1	2.1	0.33	0.039	8.5	22.5
C1	31-46	17.4	8.9	0.20	0.022	9.1	12.8
C2	46-60	18.8	13.8	0.17	0.020	8.5	12.9
Site 6							
A11	0-2	28.2	0.3	5.22	0.438	11.9	-
A12	2-5	24.2	0.4	2.42	0.234	10.3	-
B21	5-9	23.5	0.3	1.55	0.160	9.7	-
B22	9-14	21.8	0.5	1.33	0.141	9.4	-
B3ca	14-17	16.7	0.4	0.70	0.058	12.1	14.9
Cca1	17-24	15.7	0.7	0.49	0.042	11.7	16.0
Cca2	24-30	13.7	6.9	0.33	0.038	8.7	20.1
Ccs	30-46	13.4	11.4	0.18	0.028	6.4	10.5
C1	46-60	12.7	9.0	0.16	0.019	8.4	12.6
Site 7							
A11	0-2	30.2	1.1	5.45	0.451	12.1	
A12	2-4	23.8	0.6	2.88	0.261	11.0	
B21	4-8	21.8	0.5	1.96	0.191	10.3	
B22	8-14	20.5	0.5	1.01	0.109	9.3	
B3ca	14-18	18.1	0.6	0.81	0.088	9.2	5.1
Cca1	18-26	14.4	4.4	0.49	0.036	13.6	18.8
Cca2	26-32	13.3	8.2	0.33	0.027	12.2	21.7
C1	32-45	14.6	15.0	0.20	-	-	12.6
Ccs	45-60	12.7	>15.0	0.15	-	-	12.4
Site 8							
A11	0-2	39.6	0.8	6.22	0.554	11.2	
A12	2-5	32.7	0.6	4.18	0.371	11.3	
AB	5-7.5	27.7	0.5	2.41	0.221	10.9	
B2	7.5-16	24.9	0.4	1.32	0.125	10.6	3.3
Cca1	16-24	19.9	0.5	0.41	0.063	6.5	18.5
Cca2	24-36	18.9	0.5	0.24	0.044	5.5	24.0
C1	36-48	18.3	0.7	0.18	0.024	7.5	14.7
C2	48-60	17.2	0.9	0.14	0.019	7.4	18.6

TABLE VII. (Continued)

Horizon	Depth inches	Cation Exch. Cap. me./100gm.	Elect. cond. Ec.x10^3	Organic* carbon %	Nitrogen %	C/N	$CaCO_3$ equiv. %
Site 9							
A11	0-2	34.9	0.4	6.05	0.474	12.8	
A12	2-5	28.6	0.2	3.66	0.297	12.3	
AB	5-7.5	28.6	0.2	2.13	0.206	10.3	
B2	7.5-15	22.0	0.2	1.31	0.136	9.6	-
B3cal[4]	15-20.5)	13.4	0.4	0.72	0.062	11.6	24.9
B3ca2[4]	20.5-24)						
Cca	24-36	11.1	0.4	0.33	0.033	10.0	34.7
C1	36-46	10.8	0.4	0.11	0.018	6.1	33.3
C2	46-60	11.6	0.4	0.10	0.015	6.7	29.8
Site 10							
Ap	0-7	29.8	0.6	4.47	0.343	13.0	1.9
B21	7-10	20.8	0.6	2.52	0.226	11.2	1.9
B22	10-16	17.1	0.3	1.15	0.118	9.7	2.3
B3ca	16-22	16.9	0.5	0.88	0.090	9.8	14.0
Ccal	22-28		0.7	0.47	0.052	9.0	24.0
Cca2	28-40		0.6	0.31	0.031	10.0	24.7
C1	40-50		0.5	0.22	0.024	9.2	24.7
C2	50-60		0.5	0.16	0.018	8.9	24.3
Site 11							
Ap	0-5	30.7	0.4	3.97	0.316	12.6	1.2
B21	5-10	22.6	0.3	2.35	0.203	11.6	1.2
B22	10-17	14.3	0.4	0.87	0.086	10.1	1.4
B3ca	17-22	17.2	0.6	0.72	0.068	10.6	15.4
Ccal	22-28		0.4	0.49	0.049	10.0	23.9
Cca2	28-39		0.9	0.29	0.031	9.4	24.6
C1	39-48		0.8	0.20	0.021	9.5	24.2
C2	48-60		0.9	0.21	0.020	10.5	24.0

1 Horizons were named by Johnson (18) as follows: Cca2, 31-39" and C1, 39-47".

2 Horizon was named Ccal, 12-21" by Johnson (19).

3 Horizons were named by Mogen (27) as follows: A1, 0-7"; B2, 7-14"; B3, 14-18"; Cca, 18-42"; C1, 42-53"; and C2, 53-65".

4 Horizon was named Ccal, 16-24" by Mogen (29).

* All analyses on sites 1, 2 and 3 and all organic carbon analyses by the Soil Survey Laboratories.

** Sum of extractable cations.

Electrical Conductivity

The electrical conductivity of the saturation extract is shown in Table VII. Electrical conductivity is a measure of the salt content in a soil and parallels the groupings found for sodium.

Organic Carbon

Organic carbon is a measure of the organic matter content in the soil. Organic carbon percentages are shown in Table VII.

Due to cultivation at sites 1, 2, 10 and 11 comparison among the sites in the surface horizons is difficult.

The average organic carbon percentage from the surface to 24 inches is shown in Table VIII.

TABLE VIII. AVERAGE ORGANIC CARBON

Sites	1 and 2	3	4 and 5	6 and 7	8 and 9	10 and 11
Percent	1.76	1.44	2.17	2.03	2.84	2.12

Site 3 has the lowest organic carbon level, and, as noted earlier, the lowest cation exchange capacity.

The highest organic carbon level is found at sites 8 and 9. Sites 4, 5, 6, 7, 10 and 11 are about equal in organic carbon but are higher than sites 1 and 2, which are the second lowest.

Total Nitrogen

The total nitrogen percentage is shown in Table VII. At all sites there is a decrease in total nitrogen with depth. As the main source

of nitrogen is the organic matter in the soil, the relationships among the sites is the same as for organic carbon.

Calcium Carbonate Equivalent

The calcium carbonate equivalent percentages are shown in Table VII. The results indicate that the deepest leaching of calcium carbonate is at site 3. However, the horizon designations indicate that carbonate should have been at 14" and not 19". This is one of the sites where the horizon designations differ from the previous description.

Assuming the 14 inch depth for site 3, the deepest leaching of carbonate is at sites 8, 9, 10 and 11. These sites also have the highest precipitation. The other sites are all leached of calcium carbonate to about 14 inches.

The calcium carbonate equivalent in horizons of genetic lime accumulation arrange the sites in the following order of decreasing lime content: 8 and 9, 10 and 11, 1 and 2, 4 and 5, 6 and 7, and 3.

It can be seen that the calcium carbonate equivalent progressively decreases as one goes from north to south, that is, from sites 1 and 2 through sites 6, 7, 4 and 5 to site 3.

Sites 10 and 11 are not greatly different from sites 1 and 2 but sites 8 and 9 are higher in calcium carbonate equivalent than sites 1 and 2.

Summary of Laboratory Results

Sites 4, 5, 6 and 7, the border sites, have more clay accumulation, in the B horizon, are more acid in the surface, have considerably more sodium in the subhorizons, and a smaller calcium carbonate

equivalent percentage in the horizon of genetic lime accumulation than sites 1 and 2. The border sites have less clay accumulation in the B horizon, are less acidic at the surface, have more sodium in the sub-horizons and have a higher calcium carbonate equivalent than site 3. Thus the border sites appear to be between the two extremes, sites 1 and 2 and site 3, but the magnitude of these various parameters tend to associate them with site 3.

Sites 8, 9, 10 and 11 have less clay accumulation in the B horizon, are more acid, have less sodium in the lower horizons, and a higher calcium carbonate equivalent percentage in the horizon of genetic lime accumulation than sites 1 and 2.

There appear to be no large differences between sites 8 and 9 and sites 10 and 11 except that the calcium carbonate equivalent percentage is higher at sites 8 and 9.

Thus it appears that the eastern sites (8, 9, 10 and 11) should be separated from sites 1 and 2.

If the parent material at site 10 is different from sites 1 and 2, or sites 8, 9 and 11, the soils formed on site 10 type parent material should be separated from the others.

CONCLUSIONS

The purposes of this study were twofold. One purpose was to compare the characteristics and soil forming factors of the Barnes and Houdek soils and to make a recommendation as to the best place they may be separated. The second purpose was to determine how the Barnes soils of North Dakota, South Dakota and Minnesota compare.

The physical, chemical and observable field data obtained indicate that the Houdek soils should be correlated in parts of North Dakota as well as in South Dakota. However, the distance which they could be brought into the state would have to be determined in a second study.

In comparing the Barnes soils among the three states, the data obtained seem to justify the separation of the well-drained Chernozem soils, formed from Mankato age glacial till in eastern South Dakota and western Minnesota, from the northern Barnes soils.

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